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REVIEW ARTICLE

Promoting healthy hearing over the lifespan

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Abstract

Background and Aim: Comorbid conditions and unhealthy lifestyles are risk factors for auditory dysfunction, including age-related hearing loss. With a focus on adults, this paper describes a new approach to hearing health care that aims to prevent or mitigate hearing loss and related disorders, like tinnitus. Accurate diagnosis and effective management of hearing loss is best achieved with a patient-specific test battery that includes sensitive measures of peripheral and central auditory function.

Recent Findings: Within the past decade, peer reviewed research publications confirm the importance of comorbid conditions like diabetes, cardiovascular disease, and cognitive impairment as risk factors for hearing loss, tinnitus, and auditory processing disorders. Unhealthy lifestyles like poor diet, smoking, and chronic exposure to high intensity sound also contribute importantly to risk for hearing loss and tinnitus. In collaboration with physicians and other health care professionals, audiologists who recognize and address these risk factors for hearing loss have an opportunity to prevent or mitigate hearing loss in adult patients.

Conclusion: The traditional model for hearing health care service delivery relies on a rather outdated and simplistic protocol for evaluating and describing hearing loss, and a technology-focused approach for management. This paper offers an evidence-based rationale for expanding the test battery for diagnosing hearing loss, and a multidisciplinary intervention approach.

Keywords: Comorbid conditions; smoking; diet; value-added tests

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Introduction

A new approach to hearing health care

Traditionally, audiologists have devoted most of their time and efforts to the assessment and management of existing hearing loss. A child or adult is referred to the audiology clinic because someone, perhaps a physician, parent, or the patient, has concerns about hearing status. In the pediatric population, common concerns are delayed speech and language acquisition, poor school performance, or ear infections. For adults, a hearing assessment is typically scheduled because the patient is struggling with communication, particularly understanding speech in noisy listening environments. Of course, older persons represent a high proportion of adult patients in an audiology practice. The traditional audiology service approach begins with some simple tests to document or rule out a hearing loss. If a

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hearing loss is documented, the next step is a recommendation for amplification in an attempt to improve the patient's communication.

The author in this article proposes an alternative approach for hearing health care. This innovative approach precedes and extends beyond the straightforward audiological diagnosis of and intervention for hearing loss. The new approach differs from the traditional audiology clinical service delivery model in three important ways. First, it includes intensive early efforts to prevent or at least mitigate hearing loss in children and adults. Also, the efforts to prevent or minimize hearing loss employ a multi-disciplinary team approach involving the audiologist, other health care professionals and, importantly, the patient and family members. Second the diagnostic process includes a battery of value-added and evidence-based tests designed to efficiently evaluate peripheral and central auditory dysfunction, and related disorders (e.g. tinnitus). The test battery is selected to best evaluate a patient with specific auditory concerns and complaints. Finally, the new approach relies heavily on long-term patient counseling and education with the goal of minimizing risk factors for hearing loss and promoting healthy hearing over the lifespan.

Prevention or mitigation of hearing loss in children

The main focus of this review is the prevention or mitigation of hearing loss over the adult lifespan. However, the perinatal period and early childhood years offer ample opportunities to achieve the same goals. One clear example is the emphasis on early identification of hearing loss in infants and young children since about year 2000. The rationale for early hearing detection and intervention (EHDI) programs, including universal newborn hearing screening, follow up diagnostic assessment, and close monitoring of children with risk indicators for later onset hearing loss, is to identify and effectively manage auditory impairment in children to minimize communication disorders and to enhance speech, language, and educational development e.g. [1]. The same goals underlie preschool hearing screening efforts [2]. For some children, EHDI programs result in effective medical management of hearing loss and reduction or elimination of adverse communicative consequences.

There are multiple clear opportunities for preventing or mitigation pediatric hearing loss. A World Health Organization publication entitled Chronic suppurative otitis media: burden of illness and management options [3] is an excellent resource on the topic of preventing hearing loss in large populations of children, primarily with early and appropriate medical management of acute or chronic otitis media, measles and mumps, and meningitis. The document details a three-step approach for primary, secondary, and tertiary prevention of each of these etiologies for childhood hearing loss. As an example, primary prevention for otitis media includes the following steps:

- Promotion of personal hygiene and better nutrition
- Breastfeeding
- Healthier living conditions (e.g. no exposure to second hand smoke)
- Better management of upper respiratory tract infections

Secondary prevention for otitis media consists of early recognition of the disease and associated hearing loss, plus prompt treatment with antibiotics or surgery. Primary prevention for measles and mumps relies entirely on immunization, whereas both immunization and prophylaxis are included in primary prevention for meningitis.

Other well-recognized opportunities for prevention and mitigation of childhood hearing loss, and related disorders such as tinnitus, include minimization of the damaging effects of ototoxic drugs and exposure to high intensity sound. The former might involve a variety of strategies such as education of physicians about ototoxicity, recognition of risk factors for ototoxic-induced hearing loss, close monitoring for evidence of auditory dysfunction with appropriately sensitive techniques (e.g. distortion product otoacoustic emissions), and the application of otoprotective substances. Strategies and techniques for prevention of sound, noise and music induced auditory dysfunction are well-appreciated in adults, but hearing conservation programs in children have

the potential to be even more effective in preserving normal hearing. Pediatric hearing conservation programs are particularly important now given the apparent increase the prevalence of sound-induced hearing loss in school age children and adolescents e.g. [4,5].

We will devote some of the later discussion in this article on the importance of identifying and managing comorbid conditions, such as diabetes, in any effort to prevent or mitigate hearing loss in adults. It's important to appreciate that diabetes is increasingly a medical concern also in pediatric populations.

Prevention or mitigation of hearing loss in adults

Most of this review article is devoted to a discussion of an audiological strategy for preventing or at least minimizing hearing loss in adults. It would be reasonable to consider the two most common etiologies for hearing loss in adults, exposure to high intensity sound and presbycusis [6]. To be most effective, the process should probably begin in the teenage years with an emphasis on perhaps the most common factor in acquired adult hearing loss, exposure to high intensity sound. Again, the term "sound" rather than noise is used here because the risks of high intensity music are equally concerning. Audiologists should routinely include questions about exposure to sound in a patient history in effort to identify all potential risks including work-related noise, hobbies and part-time activities (e.g. power tools and equipment), recreational noise (e.g. shooting, motorcycle riding), attendance at sporting events (e.g. soccer games, motorsports), and exposure to both live and recorded music.

We will soon review in more detail excessive sound exposure along with other risk factors associated with adult hearing loss and, specifically strategies minimize resulting hearing loss. Exposure to high intensity sound is obviously one of the top etiologies for hearing loss in adults. Advancing age is the other major factor associated with hearing loss in adults. We will now critically assess the concept of age-related hearing loss, or presbycusis.

Does age-related hearing loss really exist?

Physicians and laypersons typically assume that hearing loss is almost an inevitable consequence of aging. Audiologists also routine refer to and "diagnose" age-related hearing loss, or presbycusis. Indeed, the principle that older people will develop sensorineural hearing loss has traditionally been emphasized in audiology education. Even the earliest audiology textbooks invariably included sections about presbycusis. For example, Bunch published in 1943 one of the first clinical audiology books in which pure tone audiograms for hundreds of patients were related to etiology and other clinical findings. One audiogram was described as follows: "the curve slopes gradually to the right, indicating that the hearing loss increases directly with the frequency of the stimulus tone. This is the record of the right ear of a man sixty-seven years of age. The examining otologist considered this record to be typical of the hearing losses so frequently encountered in tests of elderly persons, the so-called senile deafness of presbycusis"[7]. Similarly, Hayes Newby in the 4th edition of his popular introduction to audiology textbook states in a section on acquired causes of hearing loss:"sensori-neural impairments may be acquired at any time during life. The causative agent may be disease, injury, toxic effects of drugs, or simply the inexorable process of growing older" [8].

However, as early as the 1960s questions were raised about the concept of inevitable age-related hearing loss. I still remember as a master's level student many decades ago reading a fascinating passage in my first audiology textbook, the classic *Hearing and Deafness* (3rd edition) by Davis and Silverman [9]. The authors describe a unique study by Samuel Rosen and colleagues of "the Mabaans, a primitive African tribe who live in a remote area near the border between Sudan and Ethiopia. Their agrarian culture is that of the Stone Age and they live particularly quiet, peaceful, and well-ordered lives, go nearly naked, and eat a vegetarian diet." The authors go on to state about the Mabaans: "… they do not seem to suffer from presbycusis. The point is that the hearing of these primitive people, who live their entire lives in these quiet surroundings, is very

sensitive, even in old age and for high frequencies" [9]. Then, Davis and Silverman go on to explain that presbycusis isn't due only to noise but, rather, age-related hearing loss is the product of many factors, or comorbid conditions, such as heredity, cardiovascular disorders, lifestyle, and diet. We'll return to theme later in this article and 50 years after it was first introduced.

Efficient and accurate detection and diagnosis of auditory dysfunction

The concept of value-added tests

As summarized in Table 1, value-added tests contribute importantly and sometimes uniquely to the diagnosis and management of hearing loss and, as a result, to patient outcome. Varied criteria can be used to assess the clinical value of auditory tests. In no particular order of importance, value-added test may save time or money, and also enhance patient safety or minimize patient risk for harm. Value-added procedures that are highly sensitive to auditory dysfunction contribute to early detection of abnormalities, often before hearing loss is evident in some traditional tests, such as pure tone audiometry and simple speech audiometry. Value-added procedures that are highly specific to auditory dysfunction contribute to accurate diagnosis and localization of abnormalities, often revealing abnormalities not apparent on other test procedures. By definition, value-added tests always contribute to accurate diagnosis, effective management, and better outcome for patients with hearing loss and related disorders, e.g. tinnitus or hyperacusis.

Limitations of traditional behavioral hearing tests

Many audiologists continue to rely almost exclusively on a simple test battery first proposed more than 70 years ago soon after the beginnings of audiology as a profession [10-12]. Based on surveys over the years and reviews of billing data for adult populations in the USA [13,14], almost all patients who undergo a hearing assessment are evaluated with a rather simple test battery consisting of two pure tone threshold measures, air- and bone conduction pure tone audiometr, and two speech audiometry measures, speech reception (recognition) threshold and word recognition in quiet. Although current international surveys of clinical practice are lacking, a similar traditional yet rather limited approach to diagnostic audiology is presumably employed worldwide. We will now critically consider the clinical limitations and liabilities that are associated with each of the four procedures within this simple approach for diagnostic hearing assessment of most patients, beginning with air conduction pure tone audiometry.

Air conduction pure tone audiometry

Despite its longstanding and almost exalted stature as a relied-upon procedure for routine hearing assessment, pure tone audiometry with air conduction stimuli is characterized by at least six serious clinical limitations.

- Pure tone audiometry is a measure of one of the simplest of auditory processes, detection of sound in quiet, for sinusoids, the simplest of sounds. The audiogram does not reflect real-world hearing demands. That is, in day-to-day activities, including communication settings, no one needs to listen to pure tones in a quiet environment.
- Pure tone audiometry yields data for a remarkably tiny and inadequate sample of test frequencies. The typical audiogram depicts thresholds for six octave frequencies or, perhaps eight frequencies if inter-octave stimuli at 3000 and 6000 Hz are included. The normal human ear is capable of detecting frequencies over the range of 20 to 20,000 Hz, or 19,980 frequencies. The audiogram reflects hearing thresholds for a miniscule proportion of the frequency range for normal human hearing sensitivity, specifically 8/19,980 or 0.0004%!
- The audiogram has little relation to self-perceived hearing handicap or everyday hearing abilities e.g. [15,16]. Persons with a normal audiogram may have very serious hearing and communication problems. Obvious examples include patients with central auditory dysfunction, including auditory processing disorders, and some with auditory neuropathy spectrum disorder (ANSD). Conversely, the majority of

Table 1. Criteria for evaluating whether an audiological test adds value for a specific patient

Provides information not available from other tests: Value is always added when a specific test yields information about status of the peripheral or central auditory system that is not available from any other test. *Example:* Measurement of DPOAEs provides unique information about outer hair cell function.
Shorter test time: Clinical test time is a valuable commodity. Two procedures may meet the same clinical objective (e.g. identification of auditory dysfunction) and/or they may provide comparable information about auditory status. The procedure that requires less test time has more clinical value. *Example:* Utilization of phonetically balanced (PB) word lists with the 10 most difficult words presented first often quickly provides information about word recognition performance equivalent to typical lists of 25 PB words that require more than twice as much time.
Less risk: Minimizing patient risk and maximizing patient safety are always high priorities in clinical audiology. A test approach associated with minimal risk is preferable to another test strategy that does pose risk, assuming both approaches yield comparable diagnostic information. *Example:* Behavioral audiometric results, even in the sound field, cannot be obtained for a 9-month old infant at risk for hearing loss. ABR is an option for ruling out hearing loss, but sedation or anesthesia in a medical setting is necessary to achieve an adequately quiet test condition, with associated health risk. Combined normal results for acoustic reflex measurement with a broadband noise stimulus (threshold less than 80 dB HL) and DPOAEs (amplitudes within a normal region for test frequencies of 500 to 8000 Hz) effectively and safely rule out hearing loss that could interfere with speech and language acquisition.
Lower financial cost: Although minimizing the financial cost of audiological assessment is not as important as assuring diagnostic accuracy, it may be a factor to be considered for patients and/or in some health care delivery systems. If two procedures yield equivalent information, but the fee for one procedure is substantially lower, then the less expensive procedure adds value. *Example:* Hearing screening of a well-baby costs less when done by a technician using automated ABR technology rather than an audiologist conducting conventional ABR measurement.
Reliability and/or validity of test results: Unreliable or invalid tests do not contribute to the identification or diagnosis of hearing loss. Only tests yielding reliable and valid findings add value to hearing screening or assessment. *Example:* Reliable and valid findings are almost always possible with objective tests, such as OAEs and ABR. Objective tests (e.g. acoustic reflexes, DPOAEs, ABR) invariably add value for detection or diagnosis of hearing loss in selected patient populations, e.g. infants and young children and patients of any age with developmental delay or cognitive impairment.
Highly sensitive to auditory dysfunction: Optimal screening or diagnostic procedures have a high degree of sensitivity to auditory dysfunction, and they are preferable to tests that are less sensitive for the detection of abnormalities in the auditory system. Examples: Tympanometry and acoustic reflexes may be abnormal in a patient with middle ear dysfunction yet no air-bone gap on pure tone audiometry. DPOAEs are invaluable in assessment of patients at risk for cochlear dysfunction. Abnormal DPOAEs may document cochlea (outer hair cell) dysfunction even in patients with a normal audiogram. An abnormal ABR may suggest neural auditory dysfunction in a patient with normal pure tone sensitivity.
Site-specific information on auditory dysfunction: Optimal test procedures provide information on the site of dysfunction within the auditory procedure, rather than generalized information about an abnormality somewhere in the auditory system. *Example:* An abnormal audiogram only reflects an unspecified abnormality in auditory status, from the middle ear to the central auditory system. In cases of false hearing loss, the abnormal audiogram may inaccurately suggest auditory dysfunction. In contrast, objective auditory procedures are diagnostically valuable in part because they do provide site-specific information on auditory dysfunction.
Contributes to more accurate diagnosis: Value added tests always contribute to more accurate diagnosis of hearing loss. *Examples:* Normal DPOAE findings in an infant with an absent ABR and/or absent acoustic reflexes contribute importantly to the early diagnosis of auditory neuropathy spectrum disorder (ANSD). Abnormal speech perception in noise may contribute importantly to the diagnosis of auditory processing disorders in an adult with a normal audiogram and normal word recognition in quiet.
Contributes to more effective management: Value added tests always contribute to more effective management of hearing loss. *Examples:* In the context of a test battery, an absent auditory steady state response (ASSR) in an infant with pure tone stimulation at 110 dB HL confirms a profound hearing loss and contributes to a decision for cochlear implantation. Information about abnormal DPOAEs in a patient with bothersome tinnitus yet a normal audiogram contributes to effective counseling in the management.
Contributes to better patient outcome: Value added tests always contribute to better patient outcome. Improved patient outcome is without doubt the most important characteristic or contribution of a value-added test (s). *Examples:* Absent acoustic reflexes in a patient with modest asymmetry in pure tone audiometry prompt referral to an otologist and subsequent surgical removal of a small vestibular schwannoma with preservation of auditory function. Based on abnormal findings for speech perception-in-noise tests, an adult hearing-impaired patient is managed with amplification including an FM feature and remote microphones, plus computer based auditory training to improve speech-in-noise performance.

people with hearing loss as indicated with an abnormal audiogram do not seek audiological assessment or management, such as amplification. Two people with the same audiogram may report very different experiences with communication.

- An assortment of listener variables may compromise the reliability and validity of pure tone audiometry, and really any behavioral audiological procedure, among them motivation, cognitive functioning (including attention and memory), fatigue, and language factors that interfere with instructions for the task.
- Pure tone audiometry is an inadequate test of hearing, in the true sense of the word. The audiogram is a graph of hearing sensitivity, mostly dependent on cochlear function. Hearing, on the other hand, requires rapid processing of often complex and rapidly changing acoustical information throughout the auditory system, from the middle ear to the cerebral cortex.
- Pure tone audiometry provides essentially no information on listening abilities that are essential for effective human communication. Listening is an active process requiring effort, attention, and other cognitive functions.

Space does not permit a more detailed critique of air conduction pure tone audiometry and the multiple shortcomings of the audiogram as a primary measure of hearing status.

Readers are referred to a recent article by Musiek and colleagues [17] for an excellent critical perspective on the pure tone audiogram.

Bone conduction pure tone audiometry

Audiologists routinely measure both air- and bone conduction hearing thresholds in the initial assessment of most patients. Almost every patient undergoes bone conduction pure tone audiometry e.g. [14]. In the USA, audiologists commonly utilize the billing code for "pure tone audiometry (threshold) air and bone" or "comprehensive audiometry threshold evaluation and speech recognition", both of which include measurement of bone conduction hearing thresholds [14]. This practice is not justified clinically. For the majority of adult patients encountered in an audiology clinic, bone conduction pure tone audiometry does not add value to the diagnosis or management of hearing loss.

Middle ear dysfunction and associated conductive hearing loss, presumably documented with a valid air-bone gap, is quite unusual in an adult population. Zapala et al. [6] in a study of a large audiology and otolaryngology population (> 1500 patients) reported essentially no older adult patients with middle ear dysfunction who required referral to otology. Only 4.2% of all of the patients initially seen in an audiology clinic required referral to otolaryngology. The majority of the patients then underwent otologic workup for possible retrocochear pathology, assorted sensorineural etiologies (e.g. Meniere's disease, sudden onset hearing loss), or a cochlear implant evaluation. Margolis and Saly [18] described hearing loss characteristics in a very large population of patients (> 27,000 ears) undergoing audiological assessment in a busy otolaryngology clinic. One would expect audiologists in such a clinic to encounter a rather high proportion of patients with middle ear dysfunction. Yet, almost 60% of the population yielded audiologic and otologic findings consistent with either normal hearing sensitivity (15%) or sensorineural hearing loss (43%).

Many audiologists rely on comparison of hearing thresholds for air- versus bone conduction, the air-bone gap, for identification middle ear dysfunction and quantification of conductive hearing loss. As described below, the air-bone gap is not a reliable or valid index of middle ear status. A more direct and clinically justified approach for determining when to perform bone conduction pure tone audiometry combines patient history, otoscopic inspection, findings from physician examination, and direct audiological measures of middle ear status. Bone conduction pure tone audiometry is not indicated or clinically justified for patients meeting two or more of the following evidence-based criteria:

- No patient history of middle ear disease, including no medical evaluation or management
- Normal otoscopic findings
- No mention of middle ear abnormality in the physician examination report
- Normal tympanometry

- Normal ipsilateral or contralateral acoustic reflexes observed with the probe in each ear
- Normal otoacoustic emissions (OAEs) for low test frequencies.

Of course, the comprehensive assessment of hearing should include bone conduction pure tone audiometry for patients at risk for or with a history of middle ear disease, and for those patients with abnormal findings on direct measures of middle ear function, such as tympanometry or wide band reflectance/absorbance.

Unnecessarily performing bone conduction pure tone audiometry is not an audiological asset but, rather, a liability in the diagnostic process. There are at least four practical disadvantages or drawbacks to routinely performing bone conduction pure tone audiometry in patients lacking risk factors or clinical findings associated with middle ear dysfunction. First, the investment of precious test time yields no diagnostic return. Bone conduction pure tone audiometry with masking of the contralateral ear requires more than 5 minutes of test time [19], time that would be better spent on tests that contribute to validation of the patient's complaints, to accurate diagnosis of auditory dysfunction, and to effective management. Second, in many health care systems either the patient or a third-party health insurance carrier will be obligated to cover the cost associated with bone conduction pure tone audiometry.

Third, regularly conducting air- and bone conduction pure tone audiometry when it's not clinically justified will inevitably lead to inappropriate suspicion, or even incorrect diagnoses, of patients with conductive hearing loss due to false or spurious air-bone gaps. Building on longstanding research dating back to the 1960s [20], Margolis extensively examined the statistical chance of recording air-bone gaps or bone-air gaps at different pure tone frequencies in persons with clinically documented normal middle ear dysfunction [21,22]. Much of this research was completed during the development and validation of Automated Method for Testing Auditory Sensitivity (AMTAS) software, and clinical trials, for an automated audiometer, now available as the GSI AudioStar Pro device. Apparent air-bone gaps or bone-air gaps of 10 dB, 15 dB, or even 20 dB HL are entirely predictable from a statistical perspective, even in patients with normal middle ear status. Indeed, an absence of air-bone gap (i.e. 0 dB difference) for the four typical test frequencies of 500, 1000, 2000, and 4000 Hz occurs in less than 20% of cases. The problem with spurious air-bone gaps, that is, differences in persons with normal ear function, is most common and clinically serious when air- and bone conduction thresholds are compared at a test frequency of 4000 Hz. As Margolis notes "… our data show a 12-dB air-bone gap at 4000 Hz for manual testing and 22-dB air-bone gap for automated testing" [21].

The final concern is perhaps most important. There is a chance that routinely performing bone conduction audiometry in a futile attempt to document non-existent conductive hearing loss in a patient with strong evidence of normal middle ear function may serve to undermine patient and physician confidence in the competence and even the professional integrity of the audiologist. It would be entirely reasonable for a patient and/or the patient's physician to seriously question why an audiologist went to considerable efforts to perform a test to document middle ear dysfunction that was not suspected based on patient history, physician examination, or other audiological test findings.

Speech reception (recognition) threshold

The vast majority of audiologists invariably conduct measurement of SRT with spondee word materials for almost all patients undergoing hearing assessment. The descriptor for the most commonly-used billing code for basic hearing assessment in the USA includes verbiage for the SRT in comprehensive audiometry threshold evaluation and speech recognition. At least five minutes of test time is consumed with an explanation of the task to the patient plus the actual time required to estimate spondee threshold for each ear using rather detailed guidelines for measuring SRT [23]. Audiologists who insist on first verifying that the spondee words are familiar to the patient will require additional test time. It's important to point out at this juncture that for

selected spondee words the familiarization process does not enhance accuracy of the SRT.

The SRT provides useful information in the hearing assessment of selected patient populations, especially young or difficult-to-test children, older patients with possible cognitive decline, and patients of any age where there is a suspicion of false or exaggerated hearing loss. However, for the majority of older pediatric and adult patients undergoing clinical audiological assessment, information from measurement of the SRT does not contribute to the diagnosis of hearing loss or to decisions about management. In a review of audiological charts for over 1000 children and adults, the SRT rarely differed from the pure tone average (PTA) by more than +/- 7 dB for patients aged 20 to 70 years [24]. Referring to a large clinical study cited earlier [18], over 50% of > 16000 patients were within the age range of 20 to 70 years. And, the SRT and PTA is almost always in close agreement for patients with normal hearing thresholds [24]. The Margolis and Saly [18] study showed that normal hearing sensitivity is confirmed for at least 15% of patients in an otology clinic. The proportion of normal hearers is no doubt considerably higher in a private practice audiology setting. Agreement for the SRT and PTA in a normal hearing population is not surprising. There is really no physiological or psychoacoustic explanation for why the SRT would be significantly poorer than the PTA in a cognitively-intact adult with hearing thresholds < 20 dB HL.

Like bone conduction pure tone audiometry, it is entirely reasonable and clinically justified to perform SRT measurement selectively rather than reflexively, at least in patients within the age range of 20 to 70 years who have reasonably good pure tone thresholds. Answers to three related questions will help to guide audiologists as they consider whether to include SRT measurement in the test battery for a specific patient 1) Will information from the SRT tell me more than what I already know about this patient's hearing from other tests, such as pure tone audiometry or OAEs? 2) Will the SRT contribute to my diagnosis for this patient? 3) Will I alter the management plan for this patient based on the SRT? If the answer is "no" for each of these questions regarding a specific patient, audiologists would be well advised to refrain from measuring the SRT.

Word (speech) recognition in quiet

The fourth simple hearing test to be critically considered is word recognition in quiet. Traditionally, word recognition performance is assessed under earphones in a sound-treated room using single syllable words presented in lists of 25-words phonetically balanced with regard to occurrence of phonemes in everyday speech [16]. To be sure, patients with high frequency sensory hearing loss may experience difficulty with the task since recognition of single syllable words is heavily influenced by perception of speech sound energy in the 2000 to 4000 Hz region. In fact, scores for word recognition tests may overestimate problems some patients experience when listening to conversational speech.

The most common and serious clinical limitations or drawbacks associated with measurement of word recognition in quiet resemble those for air conduction pure tone audiometry. That is, recognition of single syllable words in an atypically quiet setting is not consistent with real world listening demands. Excellent word recognition scores do not rule out deficits in central auditory processing and, specifically, daily struggles in perceiving and understanding complex speech in noisy settings. Audiologists commonly encounter patients who emphatically state: "I can hear you easily in this quiet room, but I really have problems understanding people speak when there is background noise."

Audiologists who rely exclusively on word recognition in quiet to assess the communication ability of patients will underestimate the real-world problems that some patients experience throughout the day. Many patients whose chief complaint is difficulty with speech perception in noise understandably might question why an audiologist would spend time evaluating their word recognition in quiet. For such patients, word recognition scores in quiet will have little relation to the communication disorder that brought them to the clinic. In addition, word

recognition scores in quiet generally lack sensitivity to neural and central auditory dysfunction.

Diagnostic value of objective auditory tests and speech-in-noise tests

The idea of supplementing simple behavioral audiometric tests with additional independent procedures is certainly not novel or new. Indeed, it was clearly and effectively articulated over 40 years ago in the classic Jerger and Hayes paper "The Cross-Check Principle in Pediatric Audiology" [25]. As recently reviewed by Hall [26], the paper describes five case studies to highlight the potential for errors in the diagnosis and management of hearing loss when audiological assessment is limited to simple behavioral techniques. Expanding the crosscheck principle to patients of all ages, and taking the liberty to replace the word children with patients, results in this time-tested statement: "… simply observing the auditory behavior of [patients] does not always yield an accurate description of hearing loss. In our own experience, we have seen too many [patients] who have been misdiagnosed and mismanaged on the basis of behavioral test results alone" [25]. With the exception of OAEs, the techniques and diagnostic tests readily available to audiologists for routine hearing assessment of adults today has changed remarkably little since 1976 [16,27].

Speech in noise play an important role in application of the crosscheck principle in pediatric and adult patients. Dozens of tests of speech perception in noise are available in English and other languages. Speech-in-noise (SIN) tests are distinguished on the basis of the speech signal, or target items, that the patient must recognize and the nature of the background sound. Typical speech signals are single syllable words, meaningful sentences, and non-meaningful ("nonsense") sentences. Types of "noise" incorporated into the tests include speech-shaped broadband noise, multi-talker babble (male or female voices), competing senences, and competing messages (e.g. a story). There are also SIN tests that essentially combine word and sentence speech materials. For example, the Quick SIN test is used to determine the patient's performance in identifying 50% of key words embedded within sentences at varying levels of background noise. The Quick SIN test yields a signal (speech)-in-noise ratio (SNR) score, rather than the typical percent correct score. Manufacturers of computer based diagnostic audiometers include selected speech-in-noise tests in digital format as a feature to facilitate recorded speech audiometry in clinical settings.

Speech perception in noise tests are a more logical, sensitive, and effective measure of communication abilities than tests of word recognition in quiet. The relatively limited information about speech perception available from tests of word recognition in quiet are is also available with speech in noise tests. Speech in noise tests provide additional clinically valuable information about real-world communicative skills and deficits (see 16 for review). Results are superior in determining amplification needs and options, and also for detection of neural auditory dysfunction. The latter diagnostic benefit is substantial. As Vaisbuch et al. [28] report in a study of patients with confirmed vestibular schwannoma, performance of speech perception in noise is more sensitive than simple tests of word recognition in quiet for early detection of neural pathology. These authors note, speech in noise tests "…can replace word-recognition in quiet in most instances in the conventional audiologic test battery" allowing for better diagnosis and management of individuals with hearing loss [28].

Accumulated clinical experience unequivocally confirms that adherence to the crosscheck principle contributes to more accurate diagnosis and effective management of all patients, not just children. Unfortunately, many or more accurately most audiologists do not apply this time-honored principle in their everyday clinical practice. As already noted, objective auditory tests and speech-in-noise tests almost always add value to the diagnosis of hearing loss, and contribute importantly to management decisions. Selected clinical applications of these tests are summarized in Table 2. The optimal test battery for most patients, including adults, combines

Table 2. Selected clinical applications of under-utilized auditory procedures within the context of a diagnostic test battery

Acoustic reflexes
• In combination with tympanometry, confirm normal versus abnormal middle ear function (i.e. rule out or confirm air-bone gap
• Differentiation among types of hearing loss including conductive, sensory, neural, and brainstem
• Confirm normal versus abnormal cochlear function (with a broadband noise signal)
• Identification and diagnosis of false hearing loss (with a broadband noise signal)
• Provide evidence for loudness recruitment (with a pure tone signal)
• Identification of auditory neuropathy spectrum disorder, in combination with normal OAEs
Distortion product otoacoustic emissions
• Detection of cochlear (outer hair cell) dysfunction in patients at risk for auditory dysfunction, e.g. bothersome tinnitus, noise or music exposure, or diabetes) including patients with normal audiograms
• Monitoring for ototoxic auditory dysfunction
• Documentation of cochlear origin of bothersome tinnitus
• Early detection of ANSD (in combination with acoustic reflexes and ABR)
• Assessment of secondary cochlear abnormality in patients with acoustic nerve neoplasms
• Documentation of preservation of middle ear function in patients post-stapectomy
• Documentation of return of normal cochlear function in patients following medical management of sudden onset deafness
• Differentiation among cochlear pathophysiologic processes in Meniere's disease
Speech perception in noise
• Documentation of auditory dysfunction in patients with the chief complaint of hearing problems in noisy settings.
• Detection of auditory processing disorder in at risk patients, e.g., traumatic brain injury, cardiovascular disease
• Confirmation of auditory dysfunction in patients with normal audiogram and normal word recognition in quiet
• Identification of patients at risk for cognitive impairment and dementia

behavioral and objective measures of auditory function selected for inclusion in a patient-specific test battery based on existing clinical information, such as patient audiological and medical history, plus the patient's chief complaint. In discussing two illustrative cases at the end of the article, we will return to the importance of constructing a patient-specific test battery to assure accurate diagnosis and effective management of hearing loss and related disorders.

Comorbid conditions and auditory dysfunction

Overview of comorbid conditions

A growing body of research confirms a connection between hearing loss and a variety of chronic diseases and disorders (for reviews see 29−33). The medical term "comorbidities" is increasingly appearing in the audiological literature and also in clinical conversations about patient diagnosis and management. Audiologists have long known that specific often acute disease processes are related directly to different types of hearing loss. For example, chronic otitis media, cholesteatoma, and otosclerosis almost invariably produce middle ear dysfunction and conductive hearing loss. Sensory hearing loss is a common finding in infections and other disease processes disrupting cochlear function, such as meningitis, cytomegalovirus, and Meniere's disease. And, audiologists are well aware that neoplasms like vestibular schwannoma and non-tumor etiologies like auditory neuropathy spectrum disorder cause neural auditory dysfunction. Within the past decade, however, there has been increasing awareness and appreciation of the clinical relation between systemic diseases, especially chronic health conditions, and risk for hearing loss and related disorders, such as auditory processing deficits, tinnitus, and vestibular/balance disorders.

A PubMed literature search (www.nlm.nih.gov) with the key words "comorbid conditions" and "hearing" shows over 700 peer reviewed publications, with almost all of the papers appearing within the last 10 years. A detailed review of

comorbid conditions associated with hearing loss and related disorders is far beyond the scope of this brief review. The three objectives of the following rather superficial overview are to: 1) to alert audiologists to the importance of always considering comorbid conditions in the provision of pediatric and adult clinical audiology services, 2) remind readers that regular professional interactions with physicians, specifically the referral of patients from and to primary care and specialty physicians, is very important in audiological practice, and 3) describe how information about comorbid conditions contributes to patient-specific decisions about an appropriate test battery for the accurate audiological assessment and a multi-disciplinary strategy for management.

Peer reviewed literature reveals an assortment of diseases and disorders associated with hearing loss and related disorders. A partial list of comorbid conditions includes:

- Diabetes
- Cognitive decline and dementia, including Alzheimer's dementia
- Depression
- Other sensory impairments, e.g. vision loss
- Cardiovascular diseases (e.g. hypertension, ischemic heart disease, stroke)
- Rheumatoid and other chronic arthritis
- Hyperlipidemia
- Kidney related disease
- Chronic obstructive pulmonary disease

Data confirming the association of hearing loss with these comorbid conditions comes from many well-designed international investigations of large samples of people, including in recent years a remarkable number of papers describing systematic studies and meta-analyses. For some investigations of large populations exceeding 100,000 subjects, hearing status was based on history or subject report, rather than formal audiological assessment. However, a growing number of publications describe findings of formal audiological assessment, including measures of central auditory nervous system function, in reasonably large samples of carefully selected subjects. Interestingly, some of the papers describe the analysis of US Medicare data for claims related to hearing loss and comorbid conditions, highlighting growing concern about the health care costs associated with untreated hearing loss. The following brief review focuses only on the first four conditions from this list. The latter two conditions, depression and dual sensory loss are closely related and, therefore, combined under one heading.

Diabetes

The literature linking hearing loss to diabetes mellitus is remarkably large and rapidly expanding. Unfortunately, the prevalence of diabetes is also rapidly increasing, particularly in some developed countries like the USA and the UK. The strong research evidence on diabetes as a comorbid condition has prompted some audiologists to increase efforts to educate physicians and the public about connection between diabetes and hearing loss, and other chronic health conditions. Readers are referred to the website www.theaudiologyproject.com for more information about this worthwhile effort.

Only a few of the hundreds of peer reviewed published studies of diabetes and hearing loss are cited in this brief overview. Readers are referred to several meta-analyses and systematic reviews for a more comprehensive perspective on the linkage of diabetes and auditory dysfunction, hearing loss, and related disorders. Sensitive measures of auditory function, such as OAEs, offer evidence of auditory dysfunction in Type I or Type II diabetes, even before hearing loss is apparent on pure tone audiometry e.g. [34,35]. The most common theme in the sizeable internationally literature is a relation of sensory hearing loss with clinically diagnosed diabetes (Type II) and, more specifically, a direct connection between degree of hearing loss and the duration of diabetes since onset e.g. [31,36-39]. Not surprisingly, diabetes is often associated with other comorbid conditions, e.g. peripheral neuropathy, cardiovascular disease, or kidney disease that also put patients at risk for hearing loss [37,38].

As noted earlier, this review mentions how an audiologist's knowledge about comorbid conditions contributes to decisions about patient referrals and hearing assessment. The link between diabetes and hearing loss has direct implications

for patient referrals. Audiologists are well-advised to educate various medical disciplines, such as primary care physicians, internists, endocrinologists, and geriatric specialists, about the likelihood of hearing loss in patients diagnosed with, and undergoing management for, diabetes. Patients with diabetes should routinely be referred for audiological assessment. Likewise, audiologists encountering patients who note diabetes in their history need to verify that the patient is receiving adequate management, with appropriate referrals as indicated.

Even a basic understanding of the pathophysiology of diabetes contributes directly to decisions about the most effective test battery for audiological assessment. Diabetes is a systemic metabolic disease that can produce vascular dysfunction within the cochlea, including narrowing of the lumen of capillaries and arterioles, and changes in the stria vascularis and other structures critical for normal hearing [40]. In addition to the usual behavioral audiological procedures, a test battery for hearing evaluation of a patient with diabetes must always include distortion product otoacoustic emissions (DPOAEs), the most sensitive and specific measure of cochlear function [35].

Cognitive decline and dementia

When many audiologists think about comorbidities, the relationship between auditory function and cognitive function or dementia may immediately come to mind. Cognitive functions such as memory, attention, and processing speed play an important integral role in hearing and processing auditory information. There is now increasing international scientific recognition of a link between peripheral hearing loss and cognitive impairment. Persons with unmanaged or "untreated" hearing loss have greater likelihood of cognitive decline [41-47]. Perhaps more compelling is the strong connection between central auditory processing and cognitive decline and dementia. Over 25 years ago Strauss at al. [48] reported auditory processing disorders in patients with early onset Alzheimer's dementia. Subsequent studies confirmed that deficits in central auditory processing, were among the earliest clinical signs of dementia [49]. Now, there is substantial research evidence documenting a strong correlation between auditory processing, including performance on clinical tests of speech perception in noise, with impaired cognitive performance for attention, memory, processing speed and dementia e.g. [42-44,46,50,51].

An audiologist's knowledge about cognitive decline and hearing clearly influences decisions about patient referrals and hearing assessment. Audiologists must reach out to medical disciplines that identify, diagnose, and manage patients with cognitive impairment and dementia, among them primary care physicians, neurologists, psychiatrists, and geriatric specialists, as well as otolaryngologists, psychologists and neuropsychologists. These health professionals should appreciate the well-established relation between hearing loss and deteriorating cognitive function and also the opportunity to apply common auditory measures, like speech-in-noise tests, to identify early stages of cognitive decline before the onset of dementia. Patients at risk for or diagnosed with cognitive impairment should routinely be referred for audiological assessment. Of course, audiologists who encounter patients who show clinical evidence of cognitive decline, such as difficulty grasping the task for simple auditory tests or poor performance of measures of auditory processing, should refer the patients to health professionals who specialize in cognitive services for proper evaluation and management.

The appropriate audiologic test strategy for assessment of patients at risk for or with the diagnosis of cognitive issues unequivocally should include objective tests to validate the results of behavioral audiological assessment and also measures of central auditory functioning. At the very least, the test battery for patients with any risk factors or clinical findings suggesting cognitive impairment should include measures of central auditory functioning, such as speech-in-noise tests and perhaps also dichotic listening tests.

Dual sensory deficits and depression

Audiologists are well aware of the importance of visual skills for patients with peripheral hearing loss. Everyday face-to-face communication,

including speech perception, is typically enhanced for patients who have the benefit of visual cues. Visual skills also may influence the outcome of auditory tests that involve a picture pointing task or that require reading visually presented material (test words or sentences) in speech audiometry. Dual sensory deficits, hearing and vision loss in combination, are quite prevalent in older adults [52,53]. In addition to their difficulties with communication and daily activities (e.g. driving automobiles), patients with age-related dual sensory loss are likely to have poorer quality of life, anxiety, and clinical depression [52,54-56].

Readers will readily appreciate the clinical implications of dual loss for patients undergoing hearing assessment. Audiologists should routinely gather information from patients about vision status and professional management of impaired vision. Older patients who have hearing loss, and who report vision impairment and/or with documentation of vision impairment in medical records, are at risk for increased anxiety and decreased mental health. Audiologists should alert referring physicians to the well-established link between combined vision and hearing loss. Audiologists must also make proper health care referrals, or recommend them to the patient's primary care physician. At the least, the patient warrants referral to an optometrist and/or ophthalmologist for complete evaluation and management of the patient's visual impairment and perhaps a mental health professional (psychologist or psychiatrist). Audiologic assessment of patients with dual sensory loss must be adapted to minimize the possible impact of a vision deficit on the outcome of hearing tests. Finally, audiologists who provide services mostly to adults in a private practice setting might consider forming professional and business partnerships with an optometrist to coordinate visual and hearing services for older patients.

Concluding comments

Consideration of comorbid conditions, beginning with a comprehensive health history, should be a consistent component in the audiological assessment and management of every patient. Patients, physicians, and audiologists all reap important benefits when comorbid conditions factor into the identification, diagnosis, and management of hearing loss. Under the following heading A Five Step Clinical Approach for Promoting Healthy Hearing we will review the many and varied the advantages for all clinical parties involved.

Healthy living contributes to healthy hearing

Lifestyle is an important determinant of health. Lifestyle factors including diet, exercise, sleep, alcohol and drug abuse, and smoking play a very important role in prevention or causation of a wide range of diseases, as well as quality and length of life [57,58]. Research now clearly shows that healthy living also contributes to healthy hearing and an unhealthy lifestyle increases risk of hearing loss.

There is a growing literature on the effects of diet and smoking on hearing and related disorders. Recent large-scale population-based studies, as well as meta-analyses and systematic reviews, confirm the relationship between diet and hearing, and tinnitus e.g. [46,59,60]. A healthy diet consists of daily eating that includes ample fruit and vegetables, omega 3 fatty acids, polyunsaturated fats, whole grains, and lean protein, and adequate amounts of water. Persons with unhealthy diets tend to eat more processed foods, lipids and other fatty foods, carbohydrates, and refined sugars (see [46] and [59] for reviews).

Smoking is another unhealthy lifestyle factor that contributes importantly to the risk of hearing loss and tinnitus, in men and women. Not surprisingly, lifestyle factors like diet and smoking often inter-related with many of the comorbid conditions associated with hearing loss, including arthritis, cardiovascular disease, obesity, and a variety of other chronic health conditions e.g. [61]. And, there is a clear relationship for the added risk to hearing due to a combination of noise exposure and smoking [62,63]. The literature linking smoking with hearing loss and related disorders is substantial [60,64-67]. In addition to the well-appreciated risks for cancer, smoking and nicotine related pathophysiology includes vascular dysfunction (e.g. vasoconstriction, increased blood viscosity) with associated

hypoxia and ischemia that adversely affect cochlear function. Smoke also contains multiple toxic substances that, in the cochlea, accumulate to produce ototoxicity [64]. Nicotine even may interfere with neurotransmission and synaptic function within the neural and central auditory nervous system [68]. The substantial research data suggest that smoking negatively affects hearing for men and women, and risk for hearing loss is directly related to the "pack-years" smoked, that is, the number of cigarettes times the number of years of smoking.

Audiologists should always include questions about lifestyle in a patient history [69,70]. Simple questionnaires available for quantifying diet, such as the Healthy Eating Index [71], can be easily administered in an audiology clinic visit. The history should also provide information about other lifestyle factors, such as exercise and substance use and/or abuse, particularly smoking. The previously stated recommendations for increased communication with the patient's referring physician, and other physicians who care for the patient, about comorbid conditions apply as well to lifestyle factors. Professional collaboration with physicians and other health professionals in the holistic management of patients benefits all parties involved.

Efforts to encourage patients to eat more healthily would probably involve collaboration with family physicians and perhaps dieticians. A focus on smoking cessation would also involve the family physician, but perhaps other physicians like cardiologists and non-physician health professionals, such as psychologists trained in cognitive behavioral therapy (CBT). Clearly, patients are more effectively managed when multiple caregivers coordinate efforts to manage health and hearing. The results of several recent studies of smoking (active and passive) and hearing loss highlight the potential impact of efforts to achieve smoking cessation [66,67,72]. Hu et al. [72], who followed smokers for up to eight years, found the expected increased risk of high frequency hearing loss. However, risk of hearing loss disappeared for those smokers who quit the unhealthy habit. Lin et al. [66] also reported that risk of hearing loss decreased over time after smoking cessation.

Presumably, most physicians also would welcome the information and support from audiologists as they attempt to improve their patients' health and wellbeing. Audiologists also will benefit in many ways from a partnership with patients and physicians with the goal to improving general health and hearing health. Some of the benefits for audiologists include increased and varied patient referrals, increased and perhaps more diverse sources of clinical revenue, and more interesting and intellectually stimulating clinical experience and, almost certainly, more audiologist and patient gratification and satisfaction.

Even a cursory understanding of the negative impacts of poor diet and the varied pathophysiological effects of smoking on hearing will contribute to wise decisions regarding the most appropriate audiological test battery. The test battery for assessment of any patient with these risk factors must include DPOAEs and measures of central auditory functioning, along with traditional auditory tests.

A five step clinical approach for promoting healthy hearing

The following practical 5-step approach is proposed for audiologists to promote healthy hearing and to mitigate the risk of hearing loss for adult patients. Each step is summarized in Fig. 1.

Step 1: Identify patients at risk for hearing loss and related disorders

Audiologists and other hearing health professionals should be involved in the education of physicians and the general public about risk factors for hearing loss. This effort can take place on a local clinical level, e.g. one-to-one interactions with referring physicians and patients. However, a public health initiative should also be implemented at the community, regional, or even country-wide level. Strategies could include published articles, information disseminated via public (radio, television, newspaper) media, social media, websites for clinics and professional organizations, etc. The messages would strongly encourage referral of at-risk

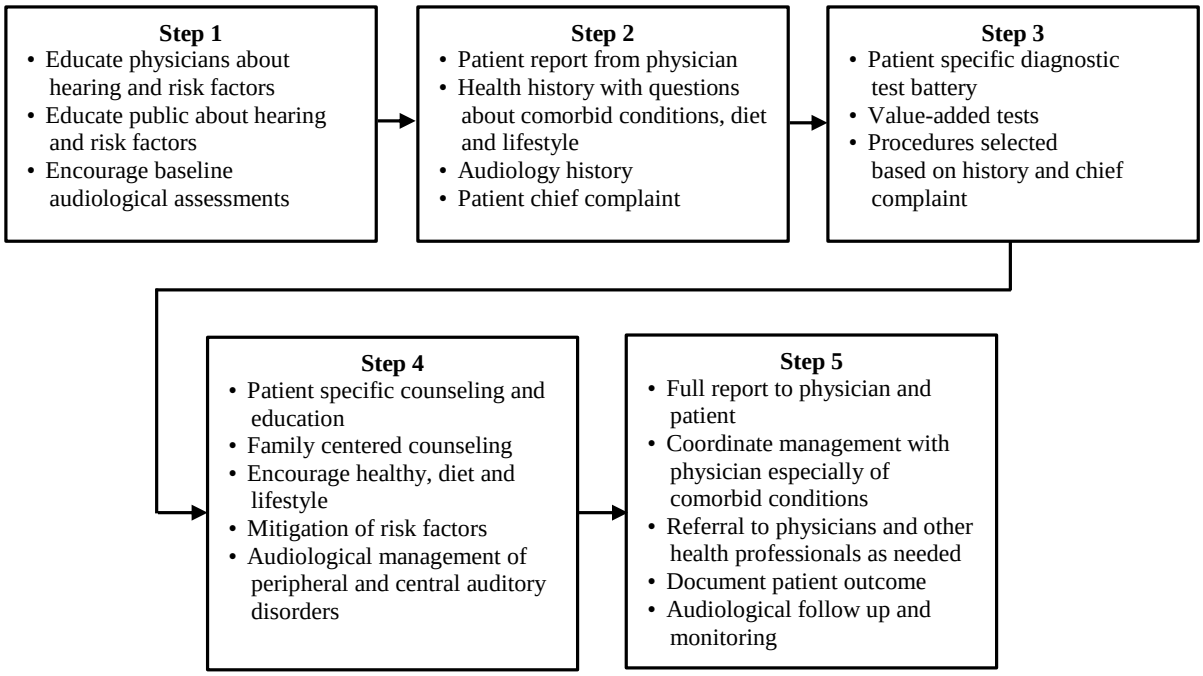

Fig. 1. Five step clinical approach for promoting healthy hearing over the lifespan.

patients for formal audiological assessment.

Step 2: Expand patient history to include general health information including comorbid conditions, lifestyle, and all risk factors for hearing loss and related disorders

As emphasized throughout this article, audiologists need to include in patient history forms detailed questions about comorbid conditions and lifestyle factors associated with hearing loss and related disorders (e.g. auditory processing disorders and tinnitus). It would certainly be appropriate for audiologists to routinely request from referring physicians a summary report of the patient's general health status, including a listing of medications and diseases under management. Answers to questions in the written patient history should be supplemented with follow-up questions and verbal information from patients and family members at the time of the clinic visit. Audiologists should be prepared to supply the patient and family with written information about risk factors for hearing loss, and simple guidelines for reducing risk.

Step 3: Evaluate auditory function with an efficient and effective diagnostic test battery with a focus on the patient's history, especially the chief complaint

Audiological assessment must be completed with a patient-specific test battery that is developed to best identify and define auditory dysfunction suspected from the history, particularly known risk factors for hearing loss and, of course, the patient's chief complaint. An evidence-based approach for effective and efficient audiological assessment includes only value-added tests that contribute directly to diagnosis and management of hearing loss. In the next section, this important point will be illustrated with two case studies.

Step 4: In addition to implementation of typical options for intervention, management should include patient-specific counseling about risk for hearing loss and related disorders plus strategies for prevention or mitigation of hearing loss

Too often an audiology clinic visit consists of the administration of an outdated "air-bone-speech" test battery to document an abnormal audiogram

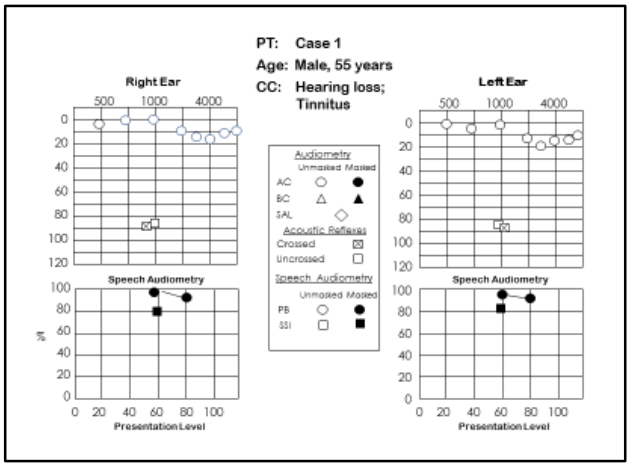

Fig. 2. Audiological findings for case 1 including pure tone audiometry, speech audiometry (word recognition and speech-in-noise tests), and acoustic reflex thresholds.

followed by a recommendation for amplification. Intervention for patients evaluated in an audiology clinic can go far beyond this simple approach to include multidisciplinary efforts to minimize risks for hearing loss, e.g. management of comorbid conditions and recommendations for lifestyle changes. Recommending and fitting hearing aids is obviously appropriate for some patients with hearing loss, but audiologists can also play an important role in preventing or mitigating hearing loss and related disorders (auditory processing disorder and tinnitus).

Step 5: Provision of audiological services should always include reports to referring physicians and referral to other health care professionals for assessment and management of comorbid conditions and unhealthy lifestyles (e.g. smoking and poor diet)

Adherence to the first four steps in the effort to promote healthy hearing over the lifespan naturally leads to step 5. Audiologists are an integral and rather unique member of a patient's health care team. Referring physicians and other physicians caring for a patient will appreciate information from a comprehensive audiological assessment, including the diagnosis and recommendations for management. Regular effective communication between and audiologist and pertinent physicians, and other health care providers, benefits all parties involved, in addition to the patient and family members.

Illustrative case reports

The follow two case reports are presented to illustrate the application of information presented in this article including the reliance on a patient-specific and value-added test battery and the importance of diagnostic information from the patient history and audiological assessment in developing an effective intervention strategy.

Case 1: 55-year old male

History: The patient was a 55-year old male referred by his primary care physician to the audiologist. The patient was employed in a post office where his duties included unloading and sorting mail. The patient's chief complaints were annoying tinnitus and difficulty hearing his wife, children, and others in noisy listening settings. The patient stated that he had never had any ear infections and had never seen a physician or audiologist for ear-related problems. The patient reported that his family physician had assured the patient that he had "normal hearing". History was remarkable for chronic exposure to recreational noise (loud engines and sports events). The patient also acknowledged smoking more than 1 pack per day for over 35 years.

Audiological findings: As depicted in Fig. 2, pure tone audiometry showed hearing sensitivity within normal limits, although hearing thresholds were slightly decreased within the 2000 to 8000 Hz region. Otoscopy was normal. Tympanometry produced normal type A tympanograms in each ear (not shown). Acoustic reflexes for a 1000 Hz signal were recorded at 85 to 90 dB HL in each ear for the ipsilateral and contralateral condition (see square symbols in audiogram graph). Word recognition scores in quiet were 96% bilaterally at 60 dB HL, as indicated with the PB symbols in the lower graph is Fig. 2. Scores for a speech-in-noise test with a signal-to-noise ratio of 0 dB (synthetic sentence identification with an ipsilateral competing message (SSI-ICM)) were 80% bilaterally. DPOAEs were recorded for test stimulus intensity levels of

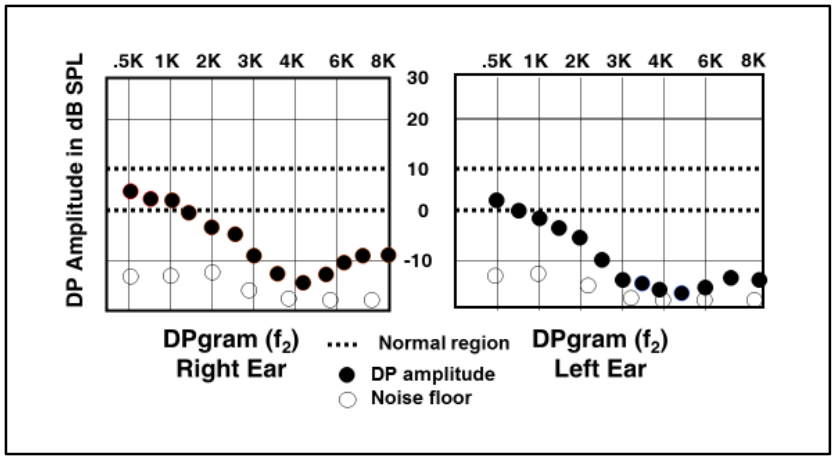

Fig. 3. Distortion product otoacoustic emissions findings for case 1.

f1 = 65 dB SPL and f2 = 55 dB SPL and for 5 frequencies per octave over the range of 500 to 8000 Hz. As shown in Fig. 3, DPOAE amplitudes were within an appropriate normal region and well above the noise floor for lower frequency test stimuli, but abnormally reduced for frequencies above 1500 Hz. Total test time for the assessment was 27 minutes.

Impressions: Although pure tone hearing sensitivity was generally within normal limits, there was a slight notching pattern for high frequency hearing thresholds. DPOAEs confirmed cochlear (outer hair cell) dysfunction bilaterally for test frequencies above 1500 Hz. Word recognition in quiet was excellent but there was evidence of abnormal speech perception in noise bilaterally.

Bone conduction pure tone audiometry was not performed because: 1) patient history revealed no concerns about ear disease, 2) otoscopic findings were normal, 3) tympanometry was normal, 4) acoustic reflexes were observed at normal levels in all test conditions, and 5) DPOAEs were normal for lower test frequencies. SRT was not estimated because the patient was an apparently cognitively intact adult with essentially normal pure tone hearing sensitivity.

Recommendations: The patient was counseled extensively about the test findings with his wife present. Both were given the opportunity to ask questions. The following recommendations were stated verbally, and also in a written report to the patient and his family physician.

- Hearing protection is important during any exposure to loud noise or music. The patient was given suggestions for hearing protection options.
- Counseling about tinnitus included a recommendation for a follow-up tinnitus consultation and evaluation with management as indicated. The patient and his wife were given written information about tinnitus and simple steps to mitigate tinnitus perception (e.g. sound enrichment).
- The patient and his wife were given suggestions for communication in noisy environments.
- Coordination with the patient's family physician about the importance of smoking cessation, with the recommendation for a formal smoking cessation program.
- Audiological reassessment in six months to monitor hearing status and compliance with recommendations. Formal assessment for auditory processing disorder (APD) will be completed if speech-in-noise deficits persist.

Comments: The audiological assessment included tests that contributed importantly to the diagnosis of cochlear hearing loss and to recommendations for management. The patient was at high risk for cochlear dysfunction due to the history of bothersome tinnitus, noise exposure, and smoking habit. Smoking also put the patient at risk for possible central auditory dysfunction. A traditional test battery consisting of air- and bone conduction pure tone audiometry and simple

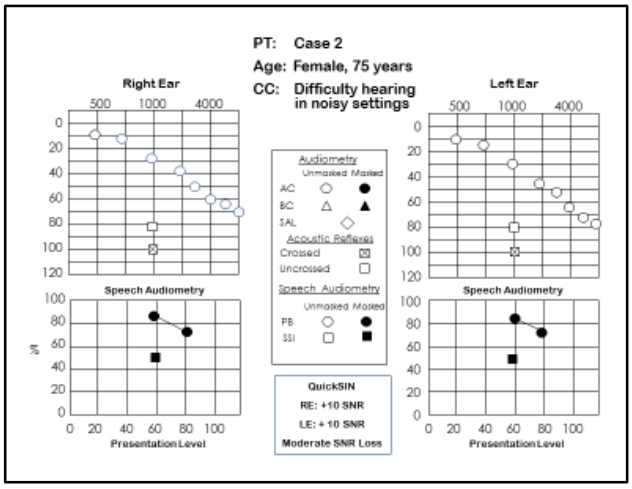

Fig. 4. Audiological findings for case 2 including pure tone audiometry, speech audiometry (word recognition and speech-in-noise tests), and acoustic reflex thresholds.

speech audiometry would not have documented cochlear dysfunction and speech-in-noise deficits. Elimination of bone conduction pure tone audiometry and SRT estimation saved > 10 minutes of test time that was devoted instead to DPOAEs and speech-in-noise testing. Findings for DPOAEs were useful in counseling the patient about the dangers to hearing posed by noise exposure and smoking.

Case 2: 75-year old female

History: The patient was a 75-year old female. She was scheduled for the assessment by her grown daughter due to concerns about hearing. The patient was a retired school teacher. Her chief complaints were difficulty hearing her daughter and grandchildren, especially in noisy listening settings. Daughter completed the history form and answered many of the verbal questions prior to the beginning of hearing testing. According to the daughter, the patient had never had any ear infections and had never seen a physician or audiologist for ear-related problems. Daughter acknowledged privately that she was concerned about her mother's poor memory and inconsistent attention. The daughter also stated that her mother's family doctor had implemented dietary management for diabetes. Aside from these concerns, the patient enjoyed reasonably good health.

Audiological findings: As depicted in Fig. 4, pure tone audiometry showed a gradual sloping hearing loss bilaterally. Otoscopy was normal. Tympanometry produced normal type A tympanograms in each ear (not shown). Acoustic reflexes for a 1000 Hz signal were recorded at 80 dB HL in each ear for the ipsilateral condition and at 100 dB HL for the contralateral condition (see square symbols in audiogram graph). SRT was 30 dB HL bilaterally, consistent with the pure tone average. Word recognition scores in quiet were 88% for the right ear and 84% in the left ear at 60 dB HL, as indicated with the PB symbols in the lower graph is Fig. 4. Scores for a speech-in-noise test with a signal-to-noise ratio of 0 dB (SSI-ICM) were 50% bilaterally. Another speech-in-noise test, the Quick SIN, revealed a moderate SNR loss. That is, the patient required a SNR of +10 dB to identify 50% of target words in sentences. DPOAEs (not shown) were abnormally reduced or absent over the range of 500 to 8000 Hz. Total test time for the assessment was 45 minutes.

Impressions: The patient showed a moderate-to-severe high frequency sensory hearing loss consistent with "presbycusis". DPOAEs confirmed cochlear (outer hair cell) dysfunction bilaterally. Word recognition in quiet was fair but the patient experienced considerable difficulty with two tests of speech perception in noise.

Bone conduction pure tone audiometry was not performed because: 1) patient history revealed no concerns about ear disease, 2) otoscopic findings were normal, 3) tympanometry was normal, and 4) acoustic reflexes were observed at normal levels in all test conditions.

Recommendations: The patient was counseled extensively about the test findings with her daughter present. Both were given the opportunity to ask questions. The following recommendations were stated verbally and also in a written report to the patient and family physician.

- The counseling session included a description of the patient's hearing loss, an explanation of auditory processing, and the recommendation for a hearing aid assessment.

- Counseling included recommendation for a follow-up APD assessment with further management as indicated. The patient and her daughter were given written information about strategies for improving communication in different listening settings.
- Communication with the patient's family physician about the relation between diabetes and hearing loss.
- Communication with the patient's family physician about the importance of a referral to psychology and possibly neurology for formal assessment of cognitive function and possible diagnosis of cognitive impairment or dementia.

Comments: The audiological assessment confirmed the diagnosis of cochlear hearing loss and central auditory nervous system dysfunction. The former was confirmed by pure tone audiometry and DPOAEs. Central auditory dysfunction was confirmed with a discrepancy between ipsilateral versus contralateral acoustic reflex thresholds and two tests of speech-perception in noise. The patient was at risk for hearing loss due to advanced age and a history of diabetes. A traditional test battery consisting of air- and bone conduction pure tone audiometry and simple speech audiometry would not have documented the central auditory deficits. Findings for speech-in-noise tests strongly suggested cognitive impairment, prompting appropriate referral for formal evaluation.

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