PREFACE

The Early Intervention of Hearing Loss in Adults

The National Institute of Deafness and Other Communication Disorders of the National Institutes of Health (NIDCD-NIH) reported that 37.5 million persons or 15% of the American population have some difficulty hearing.[1] The prevalence of hearing loss increases with age, and 2% of persons 45 to 54 years old have significant hearing loss; this increases to 8.5% for those 55 to 65 years old, 25% for those 65 to 74 years old, and 50% for those older than 75 years.[1] Normal hearing for adults has been defined as audiometric thresholds $\leq$ 20 dB HL for standard audiometric frequencies of 0.25 to 8 kHz. Only about one in five persons with sensorineural hearing loss (SNHL) seeks help for their problems,[2,3] and some individuals wait 10 years or more from the time that they first notice a problem communicating before seeking help.[4]

Waiting long periods of time to address SNHL can negatively impact the health-related quality of life (HRQoL) of individuals and their families,[5–7] and it is often associated with social isolation, increased rates of depression and anxiety, and lessened self-efficacy and mastery.[5] Untreated SNHL also is linked to hastened cognitive decline in elderly persons living independently[8] and with global brain atrophy, particularly in the temporal lobe.[9] Possible reasons for persons failing to seek help include limited accessibility to and affordability of hearing health care, particularly for unserved and underserved populations.[10] Ideally, persons with hearing impairment may avoid negative consequences of hearing loss if they seek treatment early, when their losses are mild.

This issue of *Seminars in Hearing* focuses on the prevention and early diagnosis of and the intervention for slight-to-mild hearing loss in adults from a variety of perspectives. This issue also touches on concepts related to preclinical or hidden hearing losses (HHLs). Authors contributing to this issue report on current research conducted by faculty and students in the Department of Communication Sciences and Disorders and clinical outreach programs of the John W. Keys Speech and Hearing Center (Allied Health Clinics) at the University of Oklahoma Health Sciences Center in Oklahoma City, OK. The purpose of this preface is to provide readers with some background information that sets the context for the articles in this issue of *Seminars in Hearing*.

MILD SENSORINEURAL HEARING LOSS

So, what is mild hearing loss? Definitions for mild hearing impairment vary around the world with regard to which octave frequencies are used for the calculation of pure-tone averages (PTAs) (i.e., 0.25–4 kHz), in addition to what are the lower (16–25 dB HL) and upper (39–45 dB HL) limits for mild SNHL (MSNHL).[11] For example, the World Health Organization defined mild hearing impairment as a four-frequency pure-tone average (FFPTA) of 26 to 40 dB HL over 0.5, 1, 2, and 4 kHz,[12] which was also used by Donahue

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and colleagues.[10] The prevalence of MSNHL varies based on how it is defined and ranges from one in three to one in five adults depending on which criterion is used.[11]

Several classification schemes for describing degree of hearing loss based on the pure-tone audiogram have been posited over the past 50 years. Even persons with three-frequency pure-tone averages (TFPTAs) $\leq$ 25 dB HL at 0.5, 1.0, and 2.0 kHz have sought help for their hearing losses. In 1981, Clark modified traditional hearing loss descriptors and created a new category of slight hearing loss from 16 to 25 dB HL.[13] Similarly, in 2000, Martin and Champlin recommended that the upper limits of normal hearing be 15 dB HL for adults and presented data from a leading manufacturer in which 5% of hearing aid sales were for patients whose TFPTAs were $\leq$ 25 dB HL.[14] Moreover, they explained that those patients may be victims of misclassification of the severity of their losses if they are based on the TFPTAs alone. Indeed, there is a wide variety of SNHLs and communication problems noted in persons with slight-to-mild SNHL.

Bess and colleagues[15,16] advocated for a classification of minimal hearing loss for children according to three types of losses:

- "Unilateral sensorineural hearing loss: average air-conduction thresholds (0.5, 1.0, 2.0 kHz) $\geq$ 20 dB HL in the impaired ear and an average air-bone gap no greater than 10 dB at 1.0, 2.0, and 4.0 kHz and average air-conduction thresholds in the normal-hearing ear $\leq$ 15 dB HL;
- Bilateral sensorineural hearing loss: average pure-tone thresholds between 20 and 40 dB HL bilaterally with average air-bone gaps no greater than 10 dB at 1.0, 2.0, and 4.0 kHz;
- High-frequency sensorineural hearing loss: air-conduction thresholds $>$ 25 dB HL at two or more frequencies above 2 kHz (i.e., 3.0, 4.0, 6.0, or 8.0 kHz) in one or both ears with air-bone gaps at 3.0 and 4.0 kHz no greater than 10 dB."[16]

Bess and colleagues also advocated for newer classifications of and early interventions for minimal hearing losses because of it negative impacts on the speech, language, social, behavioral, and academic outcomes for young children. The early diagnosis and intervention for slight-to-mild degrees of hearing loss are warranted for the prevention of cognitive decline and loss of HRQoL for middle-aged to older adults as well.

Varieties of Slight-to-Mild Sensorineural Hearing Loss

Adults with MSNHL may present with audiometric results that involve one or both ears, with various configurations that may be symmetric or asymmetric, congenital or acquired, and with or without (uncomplicated) additional auditory or vestibular symptoms. Bilaterally symmetrical MSNHL is one in which the FFPTA in each ear is 21 to 40 dB HL. Although the configuration of loss is approximately the same in each ear and may be downward sloping, upward sloping, flat, cookie-bite, or reverse cookie-bite shape, persons with downward-sloping configurations are the most likely to have FFPTAs of $\leq$ 20 dB HL.

Another category of MSNHL is a asymmetric hearing loss (AHL) in which one or both ears has an FFPTA of 21 to 40 dB HL, but the audiometric configurations are not the same in each ear. Asymmetric hearing loss is a red flag, and when a difference between PTAs $>$ 15 dB HL exist between ears, a full history and examination by a physician (preferably, an otolaryngologist) is recommended.[17] However, even when there are guidelines, experts have found it difficult to agree on the definition of AHL. For example, Margolis and Saly developed an algorithm, Automated Classifications of Audiograms (AMCLASS), for identifying asymmetries that is more reliable than using a panel of licensed audiologists in determining asymmetric hearing losses.[18] Their initial set of rules for identifying AHL between ears was: (1) $>$10 dB HL threshold difference at three octave frequencies, (2) $\geq$15 dB HL difference at two octave frequencies, or (3) $>$20 dB HL difference at a single octave frequency. They found that about 50% of the audiograms in their database were classified as AHLs, which included those that were mild.

There are at least two other possible subclassifications of mild AHL. One possibility is unilateral MSNHL in which one ear has a mild

loss and the other ear is normal. Another possibility is one in which one ear has a MSNHL and the other has a more severe loss with an FFPTA $\geq$ 41 dB HL. Even though methods of identifying AHL have been developed, there is no universally accepted definition of a medically significant AHL. Some algorithms have been developed that account for patient factors (age, sex, and noise exposure history) in identifying persons with vestibular schwannomas.[19] Although the etiologies of these hearing losses are often not known, neoplasms, strokes, autoimmune disorders, infections, and Meniere's disease need to be ruled out, particularly if losses are sudden onset, or rapidly progressing, or complicated with the presence of other symptoms.[20]

Indeed, adults with complicated slight-to-mild SNHL do often present with other auditory symptoms, some of which require immediate medical attention. Other patients may have clinically significant tinnitus that may be more disabling than their loss of hearing sensitivity. In this issue of *Seminars in Hearing*, Kimball and colleagues[21] report on what factors predict treatment pathways for patients with clinically significant tinnitus and slight-to-mild SNHL who presented to the Tinnitus and Hyperacusis Clinic in the John W. Keys Speech and Hearing Center (Allied Health Clinics) at the University of Oklahoma Health Sciences Center in Oklahoma City, OK. Kimball and colleagues were surprised to find that 67% of the specialty clinic's caseload had slight-to-mild hearing losses. They found that many patients with significant tinnitus and/or hyperacusis were surprised to find that they indeed had a hearing loss as well.

Treatment for Mild Sensorineural Hearing Loss

According to MarkeTrak VIII, only 1 in 10 persons with mild hearing loss gets hearing aids compared with 4 in 10 of their peers with moderate-to-severe impairments.[22] The Marke Trak studies, classification of mild hearing loss was made through self-report surveys (e.g., number of impaired ears, ratings of subjective hearing loss, difficulty hearing in noise, and scores on the Better Hearing Institute Hearing Check[23]) that placed respondents into decile groups. One of the reasons reported for not pursuing amplification by persons with mild hearing losses was that they were advised not to by their health care providers. For example, 20 to 25% of persons with mild hearing loss reported that their family doctors, otolaryngologists, or audiologists told them that hearing aids would not help.[22] Similarly, approximately 35% of the sample with mild hearing loss was told by those same health care providers to wait and be retested before pursuing amplification.[22] Health care providers in the United States are not the only ones providing this type of recommendations about amplification to adults with MSNHL, as patients with MSNHL in other countries have reported receiving similar advice from health care providers.[24] If this is true, then these health care providers need to be reminded about the negative impacts of even MSNHL on patients' overall HRQoL and the potential benefits that are available from today's high-quality hearing aid technology for patients with any degree of loss. Continuing education may be necessary to help prevent health care providers from giving patients outdated, inappropriate, or inaccurate information and recommendations that could delay them from pursuing amplification.

Another reason why persons with MSNHL may not seek amplification is a lack of accessibility to and affordability of hearing health care.[10] Several years ago, the NIDCD-NIH assembled a research working group on Accessible and Affordable Hearing Health Care for Adults with Mild to Moderate Hearing Loss for the purpose of developing a research agenda to increase access to hearing health services and hearing aids.[10] In 2016, the National Academies of Sciences, Engineering, and Medicine (NASEM) assembled an expert committee to study the affordability and accessibility of hearing health care for adults in the United States.[25] This group recommended evidence-based key institutional, technological, and regulatory changes to accomplish its goals, one of which was to increase accessibility to hearing aids.[26] For example, the NASEM, in addition to the President's Council of Advisors on Science and Technology (PCAST),[26,27] recommended that the U.S. Food and Drug Administration (FDA) develop a classification

of over-the-counter (OTC) wearable hearing instruments for use by adults with mild-to-moderate hearing losses. Recently, the Over-the-Counter Hearing Aid Act of 2017 included many of the recommendations from the NASEM[25,26] and PCAST.[27,28] The American Academy of Audiology (AAA)[29] and the American Speech-Language-Hearing Association (ASHA)[30] published position statements about OTC hearing aids and generally supported the notion of OTC devices, but only for patients with MSNHL. In this edition of *Seminars in Hearing*, Jilla and colleagues summarize issues of accessibility to and affordability of hearing health care, particularly for those with MSNHL.[31] They present a balanced view and raise important questions about direct-to-consumer (DTC) OTC models for those with MSNHL. In a second article, Jilla and colleagues review evidence in peer-reviewed journals regarding the use of OTC devices and various delivery models for adults with MSNHL.[32]

Audiologists are often faced with counseling persons with MSNHL about amplification based more on their clinical experiences with patients rather than on scientific evidence. In a recent systematic review, Johnson and colleagues found only 10 studies in the peer-reviewed literature that met inclusion criteria relevant to this topic and some of them were 20 years old and did not include advanced digital technology (ADT) hearing aids.[33] Recently, Cox and colleagues[34–37] reported outcomes from studies that compared entry- to premium-level ADT hearing aids for patients with mild and moderate SNHL. Although the findings for persons with MSNHL were similar to those with moderate losses, outcomes were not reported separately for the group with MSNHL. Thus, additional studies are needed to describe characteristics of and outcomes for patients who have MSNHL who have become successful users of ADT hearing aids. Indeed, it is difficult to support DTC OTC devices that are provided to patients with MSNHL when data are not currently available that show outcomes for ADT hearing aids used by those with MSNHL. In this issue of *Seminars in Hearing*, Johnson and colleagues[38] provide preliminary data from a sample of ADT users with MSNHL. They summarize important patient demographics, hearing-aid acquisition/use characteristics, and outcomes achieved with the devices dispensed through a private practice with extensive auditory rehabilitation and follow-up.

HIDDEN HEARING LOSS AND/OR COCHLEAR SYNAPTOPATHY

Some readers may consider our comments about identifying, diagnosing, and treating hearing losses when they are still only mild as being aggressive and perhaps promoting intervention to prevent the insidious effects of untreated SNHL before it is necessary. However, two new classifications of auditory dysfunction (i.e., HHL and cochlear synaptopathy [CS]) are changing the way hearing loss is viewed, diagnosed, and treated and may impact damage risk criteria that are used in hearing conservation programs for occupational and nonoccupational noise. Briefly, HHL is not detected by standard audiologic evaluations in that a patient may have normal pure-tone thresholds from 0.25 to 8.0 kHz, but have a loss of hearing sensitivity in the ultra-high frequencies (i.e., from 10.0 to 16.0 kHz). Therefore, the hearing loss is hidden because standard audiometric evaluations do not routinely include frequencies above 8.0 kHz, which measure damage to sensory hair cells at the very base of the cochlea that may occur from excessive noise exposure.

Noise exposure may result in audiometric threshold shifts that can be temporary (TTS) or permanent (PTS). In the past, hearing health care professionals were not terribly concerned about TTS, as hearing thresholds eventually returned to preexposure levels on standard audiometric evaluations. However, Kujawa and Liberman found that mice exposed to mild acoustic trauma and that demonstrated only a TTS presented with permanent deafferentation of inner hair cell ribbon synapses of more than 50% when measured at the base of the cochlea; this is also known as CS.[39] Other studies have shown that aging mice progressively lose spiral ganglion cells, synaptic structures, and cochlear nerve terminal boutons.[40] Moreover, Fernandez and colleagues demonstrated a synergistic effect of age and noise when mice that had been exposed to noise that caused hair cell loss and CS early in life demonstrated

greater synaptopathic changes with age than exemplars in a control group that had experienced nondamaging exposure levels.[41]

Noise may damage the cochlea in a variety of ways, one of which is oxidative stress. Excessive noise exposure is a stressor to the cochlea, which even under normal conditions, functions at high metabolic rates. The outer hair cells (OHCs) require a great deal of energy, or adenosine triphosphate (ATP), as they expand and contract along with basilar membrane movement in sharpening the traveling wave. Similarly, the stria vascularis requires energy to maintain the endocochlear potential and the ionic composition of endolymph.[42,43] The OHCs and stria vascularis have ample amounts of mitochondria, which produce ATP through phosphorylation of adenosine diphosphate involving their electron transport chains.[44] Most of the oxygen needed for this process is used under normal cellular functioning; the remaining oxygen turns into reaction oxygen species (ROS) (e.g., superoxide or hydrogen peroxide) that can damage the cochlea and send it into overdrive, which can disrupt blood flow.[44] Fortunately, mitochondria have antioxidants within them that serve to reduce normal amounts of oxidative stress caused by ROS and free radicals, major contributors to apoptosis and necrosis of sensory hair cells.

Kujawa and Liberman posited that CS is a form of HHL for three reasons: (1) extensive neural degeneration does not show up on the traditional audiogram, (2) it is difficult to visualize synapses using standard histopathological techniques, and (3) spiral ganglion cells survive for years despite their loss of connections to sensory hair cells.[45] Kujawa and Liberman suggested that the survivability of spiral ganglion cells long after deafferentation provides an optimal therapeutic time window for intervention to restore ribbon synapses.[45] In fact, preclinical studies in animal models of hearing have shown the effectiveness of antioxidants in protecting the cochlea against noise.[46,47] Additionally, a group at Harvard Medical School has shown that delivery of neurotrophin-3 to the round window or its overexpression is successful in preventing and treating CS and noise-induced hearing loss (NIHL) in animal models.[48–50] However, translation of successful interventions in preclinical studies using animal models to the clinical use with humans mandates development of an audiological test battery that is sensitive to and specific for CS. A test battery for CS is needed not only to document efficacy of therapeutic interventions for this condition, but also for audiologists who have patients with complaints of not being able to hear well, difficulty understanding speech in noise, and/or tinnitus, yet present with pure-tone audiometric thresholds $\leq$ 15 dB HL from 0.25 to 8.0 kHz. Patients with auditory dysfunction despite normal hearing sensitivity are thought to have CS and have been discussed in the literature from a variety of perspectives; they may also possess central auditory processing dysfunction. In this issue of *Seminars in Hearing*, Barbee and colleagues[51] present the results of a systematic review of noninterventional studies that used audiologic measures in animal and human models of hearing to inform the development of a test battery for CS.

One cross-sectional study assessed CS in young musicians and nonmusicians with normal hearing who were considered to be at high versus low risk, respectively, for this condition based on their history of noise exposure.[52] Surprisingly, significant differences between the groups were found in that the summating-to-action potential ratio of the musicians was nearly twice that of the nonmusicians. In addition, musicians had poorer speech recognition in noise with and without time compression or reverberation than their nonmusician peers. Results of that study suggested that young musicians may be at risk for and/or actually have CS, which underscores the importance of hearing conservation programs in schools. One of the limitations of hearing conservation programs is the lack of adherence to recommendations for adopting healthy hearing behaviors (e.g., not wearing hearing protection despite warnings about NIHL). The Hearing Evaluation Rehabilitation and Outcomes Laboratory in the Department of Communication Disorders at the University of Oklahoma Health Sciences Center sponsors the *Adopt-A-Band* program for the Pride of Oklahoma Marching Band. In this issue of *Seminars in Hearing*, Seever and colleagues report on a single-blinded, randomized controlled trial on the

effectiveness of including information about HHL in the *Adopt-A-Band* program on college band members' attitudes toward healthy hearing behaviors.[53]

CONCLUSION

In summary, early intervention for HHL and MSNHL in adults is a timely and important topic. The purpose of this preface was to provide some background information for this issue of *Seminars in Hearing*. We hope that you enjoy it!

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