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Michael Valente
Washington University School of Medicine in St. Louis

Karen Mispagel
Washington University School of Medicine in St. Louis

L. Maureen Valente
Washington University School of Medicine in St. Louis

Timothy Hullar
Washington University School of Medicine in St. Louis

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Problems and Solutions for Fitting Amplification to Patients with Ménière's Disease

Michael Valente*
Karen Mispagel*
L. Maureen Valente†
Timothy Hullar*

Abstract

Fitting amplification to a patient with Ménière's disease (MD) can present several challenges to the dispensing audiologist. These challenges include the presence of fluctuating hearing loss, a rising audiometric configuration, unilateral or asymmetrical hearing loss, reduced dynamic range, and reduced word-recognition scores. The presence of any one of these characteristics could create obstacles for a successful hearing aid fit. The presence of most if not all of these characteristics in a single patient can readily challenge the skills of even the most experienced dispensing audiologist. In addition to the audiometric challenges, this patient population has the added psychological problems associated with feeling ill due to the nausea secondary to vertiginous attacks and the anxiety associated with the unpredictable nature of the course of these attacks. This paper summarizes numerous strategies and technologies that could be implemented by the audiologist to address these unique challenges and provide a greater opportunity for a successful hearing aid fit. These suggestions include (1) advantages offered by digital signal processing; (2) using directional microphones and assistive listening devices to improve speech recognition in noise; (3) using wireless hearing aids as well as the bone anchored hearing aid; (4) counseling patients on the realistic expectations from amplification in noisy listening situations and for those with poor speech recognition; (5) using multiple programs for patients with fluctuating hearing loss; and (6) offering suggestions on programming the frequency-gain/output response for a rising configuration.

Key Words: Amplification, digital signal processing, directional microphones, loudness discomfort level, Ménière's disease

Abbreviations: ALD = assistive listening device; BAHA = bone anchored hearing aid; BB = broadband; BICROS = bilateral contralateral routing of the signal; BILL = base increase at low level; BTE = behind the ear; CCT = California Consonant Test; Cf = crossover frequency; CK = compression kneepoint; CR = compression ratio; CROS = contralateral routing of the signal; DR = dynamic range; DSP = digital signal processing; FM = frequency modulated; HP = high pass; ITC = in-the-canal; ITE = in-the-ear; LDL = loudness discomfort level; LFHL = low-frequency hearing loss; LP = low pass; MD = Ménière's disease; NAL-R = National Acoustic Laboratories–Revised; OE = occlusion effect; PTA = pure-tone average; SNR = signal to noise ratio; TILL = treble increase at low level; WDRC = wide dynamic range compression

Sumario

La amplificación de un paciente con enfermedad de Ménière (MD) ofrece varios retos al audiólogo que adapta auxiliares auditivos. Estos retos incluyen la presencia de una hipoacusia fluctuante, una configuración audiométrica en ascenso, una pérdida auditiva unilateral o asimétrica, un rango dinámico

*Department of Otolaryngology—Head and Neck Surgery, Washington University School of Medicine; †Program in Audiology and Communication Sciences at Washington University School of Medicine

Michael Valente, Department of Otolaryngology—Head and Neck Surgery, Washington University School of Medicine, Box 8115, 660 S. Euclid Ave., St. Louis, MO 63110; Phone: 314-362-7457; Fax: 314-747-1531; E-mail: valentem@ent.wustl.edu

reducido, y de puntajes disminuidos en el reconocimiento de palabras. La presencia de cualquiera de estas características podría crear obstáculos para la adaptación exitosa de un auxiliar auditivo. La presencia de la mayoría, sino de todas estas características en un único paciente, desafía las habilidades hasta de aquellos audiólogos con mayor experiencia. Además de los retos audiológicos, esta población de pacientes muestran los problemas psicológicos adicionales asociados con sentirse enfermos debido a la náusea secundaria a los ataques vertiginosos, y a la ansiedad asociada con la naturaleza impredecible del curso de dichos ataques. Este artículo resume numerosas estrategias y tecnologías que pueden ser implementadas por el audiólogo para manejar estos desafíos singulares y proporcionar una mejor oportunidad para lograr una adaptación exitosa. Estas sugerencias incluyen: (1) las ventajas ofrecidas por el procesamiento digital de la señal; (2) la utilización de micrófonos direccionales y de sistemas auditivos de apoyo para mejorar el reconocimiento del lenguaje en ruido; (3) el uso de auxiliares auditivos inalámbricos al igual que de auxiliares auditivos ósteo-implantados; (4) la consejería a los pacientes para lograr expectativas realistas sobre la amplificación en situaciones ruidosas y para aquellos pacientes con pobre reconocimiento del lenguaje; (5) el uso de múltiples programas para pacientes con hipoacusias fluctuantes; y (6) la oferta de sugerencias para programar la respuesta de ganancia frecuencial/salida para una configuración en ascenso.

Palabras Clave: Amplificación, procesamiento digital de la señal, micrófonos direccionales, nivel molesto de sonoridad, Enfermedad de Ménière

Abreviaturas: ALD = dispositivo auditivo de apoyo; BAHA = auxiliar auditivo ósteo-implantado; BB = banda ancha; BICROS = conducció contralateral bilateral de la señal; BILL = incremento basal a bajo nivel; BTE = retroauricular; CCT = Prueba de consonantes de California; Cf = frecuencia de cruzamiento; CK = rodilla de compresión; CR = tasa de compresión; CROS = conducción contralateral de la señal, DR = rango dinámico; DSP = procesamiento digital de la señal; FM = frecuencia modulada; HP = pasa alto; ITC = intra-canal; ITE = intra-auricular; LDL = nivel molesto de sonoridad; LFHL = hipoacusia de bajas frecuencias; LP = pasa bajo; MD = enfermedad de Ménière; NAL-R = Laboratorios Nacionales de Acústica – revisado; OE = efecto de oclusión; PTA = promedio tonal puro; SNR = tasa señal/ruido; TILL = incremento de agudos a bajo nivel; WDRC = compresión de rango dinámico amplio

PROBLEMS ASSOCIATED WITH HEARING AID FITTING FOR MÉNIÈRE'S DISEASE

The focus of this section of this special issue of the *Journal of the American Academy of Audiology* relates to the utilization of current technology for the diagnosis and treatment of patients with Ménière's disease (MD). In this spirit, what follows is an overview of the challenges and opportunities facing the dispensing audiologist when fitting current hearing aid technology to patients with MD. Some of the information will be opinion based upon the collective clinical experience of the authors (i.e., anecdotal). It may be of some importance to the reader to recognize that the first and third authors have over 25 years of fitting experience with the third author spending three years as an audiologist in a vestibular laboratory. The fourth author is an otologist at a large medical school, and the second author is an audiologist with fours years of experience at a large medical school. Finally, when possible, information will be based upon the limited evidence published in the literature.

Patients with MD can create unique challenges and opportunities for the dispensing audiologist. These challenges include the presence of episodic vertigo, tinnitus, sensation of fullness, unilateral or asymmetrical hearing loss, fluctuating hearing loss, poor word recognition, rising audiometric configuration, and reduced dynamic range (DR) (Johnson and House, 1979; Mateijsen et al, 2001). In addition to these audiometric challenges, MD patients often exhibit the added psychological problems associated with feeling ill due to the nausea and vomiting caused by the vertiginous attacks as well as the anxiety associated with the unpredictable nature of when the next attack will occur and how long it will last. Thus, when caring for MD patients, the dispensing audiologist must deal with both physical and emotional issues that are not typically present with most other patient populations. Unfortunately, an inexperienced audiologist oftentimes is so focused on "doing what's right" to correct the hearing loss that he is oblivious to the fact that the patient may be more interested in feeling better than hearing better. Working with MD patients requires an empathetic audiologist who will be sensitive to the emotional issues of the patient before tackling the amplification issues.

ADVANCES IN TECHNOLOGY THAT MAY BE BENEFICIAL TO MD PATIENTS

Hearing aid fittings are becoming increasingly more rewarding for patients with a wide variety of hearing losses due to the continued advances in hearing aid technology. Among these advances is continued improvement in the "features" available via digital signal processing (DSP). DSP, in comparison to analog signal processing, can provide:

1. *Greater flexibility in fitting difficult cases due to the availability of two to twenty bands/channels* of signal processing for increased flexibility in shaping the frequency-gain/output response. The increased number of channels of compression can significantly improve the fitting of hearing aids for hearing losses with reduced DR that typically change as frequency changes. For the purposes of this article, the term "band" refers to the number of "handles" available in the fitting software that the audiologist can manipulate to program the frequency/gain response of the hearing aid. The greater the number of bands, the greater the flexibility the audiologist has in programming the frequency/gain response of the hearing aids. In current hearing aids, the number of bands ranges between two and twenty. The term "channel" refers to the number of frequency regions within the hearing aid where the same signal processing takes place (i.e., compression). In current hearing aids, this can range between two and twenty.
2. Exceptionally *low compression kneepoints (CK)* allow for increased amplification of lower intensity input levels for greater audibility. In addition, most DSP hearing aids have *expansion* below the CK to reduce the microphone noise that can often be bothersome for patients with normal or near normal hearing in the low frequencies. Also, both DSP and analog signal processing can provide level dependent compression (i.e., less gain as the input level increases) for greater comfort when listening at higher input levels. Depending upon the number of channels, this level dependent compression can change either the entire frequency-gain/output response or narrower sections of the frequency-gain/output response. In addition, some hearing aids allow the audiologist to independently program the gain/output for lower, average, and/or higher input levels to assure the user that lower input levels are audible and the higher input levels are not uncomfortably loud. That is, DSP provides improved ability to allow the wide range of input levels to be compressed into the reduced DR of the patient. The change in gain/output as the input level varies is directly related to the compression ratio (CR), CK, and the number of channels of compression.
3. *Improved ability to control feedback* to provide greater headroom (i.e., more gain) in the high-frequency region for improved word recognition and decreased embarrassment. As a general rule, the greater the number of channels, the more effective the feedback management will be in maintaining speech intelligibility because feedback typically occurs in the frequency regions providing the greatest contribution to speech

intelligibility. Thus, with a greater number of channels, a narrower "slice" of the high-frequency gain/output will be impacted by the presence of feedback and thus a wider segment of the high-frequency response will be processed to provide amplification. In fact, the presence of feedback management may allow the audiologist to provide an earmold/case with a wider vent that will act to reduce the occlusion effect (OE).

4. *Improved listening comfort in noise due to the introduction of "noise reduction" algorithms.*
5. *Improvements in directional microphones* for significantly improved recognition of speech in noise. Currently, hearing aids are available with as many as three microphones in behind-the-ear (BTE) products and two microphones in all other designs with the exception of completely-in-the-canal. In addition, DSP allows for the real-time calibration of these microphones to provide optimal performance at all times.
6. A recent reintroduction of *wireless technology* in contralateral routing of the signal (CROS) and bilateral routing of the signal (BICROS) designs to provide improved cosmetic acceptability and convenience for patients with unilateral and asymmetrical hearing loss.
7. Finally, the combination of DSP and wireless technology has been utilized with *assistive listening devices (ALDs)* for better performance in noisy background situations.

The major purpose of this article is to illustrate how some of these recent advances can be used to improve the recognition of speech in quiet and noise for patients with MD.

UNILATERAL OR ASYMMETRICAL HEARING LOSS

Often, patients with MD have hearing loss in one ear and normal hearing in the opposite ear (i.e., unilateral hearing loss). Other MD patients may have hearing loss in one ear due to the MD, but also have some degree of hearing loss in the opposite ear caused by something other than MD (i.e., asymmetrical hearing loss). Although not usual, it is possible to evaluate a patient with bilateral MD.

When it is decided that the MD ear in unilateral or asymmetrical cases is unaidable (i.e., very poor word recognition, very narrow DR; profound hearing loss), the audiologist might consider counseling the patient on CROS amplification with an open mold in the better ear for the unilaterally impaired patient. BICROS amplification with a more closed mold might be considered for the bilateral asymmetrically impaired patient. It must be emphasized that if CROS amplification is considered, then the highest probability of user acceptance will occur when there is some degree of high-frequency hearing loss in the better ear. Reduced patient acceptance for CROS amplification will likely occur if the hearing in the better ear is normal because the sound quality of the amplified sound may be judged as too tinny (Harford and Barry, 1965; Harford and Dodds, 1966; Harford, 1969).

CROS or BICROS amplification is offered in wired and wireless configurations. For several years, the wireless option was not available because the manufacturer owning the patent was no longer in business. Recently, the wireless option has been reintroduced and is now offered by at least three manufacturers. One of these manufacturers has introduced wireless CROS and BICROS hearing aids in BTE-to-BTE, BTE-to-in-the-ear (ITE) and ITE-to-ITE configurations. In addition, all of these new wireless models have DSP with all of the advantages provided by DSP (i.e., multichannel compression, multiband frequency-gain shaping, multiple programs, feedback management, etc.). Unfortunately, most of these companies do not currently provide directional microphones for enhanced performance in noisy listening environments, but this will likely change in the near future.

A recent fitting option for patients with unilateral hearing loss where hearing is unaidable is the Bone Anchored Hearing Aid (BAHA) (Wazen et al, 2001; Wazen et al, 2003; Niparko et al, 2003). In this fitting, a titanium screw and abutment are surgically implanted into the mastoid of the unaidable ear. For the adult population, the BAHA device is fitted three months after surgery. Two of the authors of this manuscript have had the opportunity to fit the BAHA to several patients with unilateral hearing loss having prior experience with CROS amplification. The results with these patients have been quite satisfying in that the patients felt their performance with the BAHA was significantly better than their prior experience with CROS. In the very near future, a DSP version of this device with built-in directional microphones will be introduced. The current BAHA is an analog device where the dual microphone is attached as a fitting option.

FLUCTUATING HEARING LOSS

When the authors select and adjust hearing aids for the "typical" adult patient, the magnitude and configuration of hearing loss identified at the initial examination usually remains stable over a relatively long period of time. Thus, programming the hearing aids is often straightforward where the frequency-gain response of the "base" program (typically Program 1) is adjusted to some valid prescriptive target (corrected for binaural summation and conductive/mixed hearing loss) and identified as being beneficial for "quiet" listening. Then, if the hearing aids have multiple programs, the various programs are adjusted based upon the "base" program for quiet listening using omnidirectional microphones (Program 1) and directional microphones (Program 2) for enhanced listening in noisy listening environments. Other programs, if available, might be programmed for telephone communication (acoustic or electromagnetic), listening to music, or some other purpose as dictated by the patient's listening environment.

When fitting a patient with MD, the utilization of the multiple memories can often take on a different strategy. It is not uncommon to use the various programs for setting the frequency-gain/output response to the repeated audiograms that reports the change in hearing as a result of the fluctuating hearing loss often found in MD. For example, one common strategy used in our clinic is to place an appropriate frequency-gain/output response in Program 1 for "best" hearing and then place into Program 2 an appropriate frequency-gain/output response for the "poorest" hearing that typically follows a vertiginous episode. In this manner, the patient can access the appropriate program that more accurately represents the current hearing level. Clearly, if several hearing tests are performed and a variety of hearing losses between "best" and "worse" is found, and the hearing aids have more than two programs, then these additional frequency-gain/output responses can be placed in the other programs.

POOR WORD RECOGNITION

There is some controversy on the issue of the presence/absence of unexpected poor word-recognition scores (i.e., word-recognition score is poorer than would have been predicted based on the magnitude and configuration of the hearing loss) in MD. Johnson and House (1979) reported in 95 MD patients that the word-recognition score was 72% or better in 74% of the patients. Only 11% had scores that were 50% or poorer. In a study by Mateijsen et al (2001) on 111 patients, they could find only two ears where the resulting word-recognition score was poorer than predicted based on the average hearing loss. Thus, it may be that the word-recognition score in patients with MD may not be any different than the word-recognition score an audiologist might find in a non-MD patient with identical hearing loss. If, however, poor word recognition is present, then the audiologist should consider counseling on realistic expectations from amplification and ALDs and suggest enrollment in an auditory rehabilitation program. It needs to be emphasized that recommending an aural rehabilitation program should be considered for all patients and not just those patients with poor word recognition.

Realistic Expectations

Each audiologist has his own favorite manner in which to convey the idea of realistic expectations from amplification. What follows are *two* examples of how the authors attempt to counsel their patients on the realistic benefits from amplification.

In the first example, the authors emphasize *three* points. First, *it is* realistic to expect aided performance in quiet listening situations to be significantly better than unaided performance. Second, *it is* realistic to expect aided performance in *noisy* listening situations to be significantly better than unaided *if* the unaided pure-tone average (PTA) is approximately 35 dB HL or poorer and there is greater loss in the higher frequencies. If the PTA is better than 35 dB or if the hearing loss is flat, then the patient may not perceive improvement in aided performance in noise relative to their unaided performance (Magnusson et al, 2001). Third, *aided performance in noise, however, will not be as good as aided performance in quiet.* Further, the authors counsel the patient that persons with normal hearing can not hear as well in a noisy restaurant as they do in the quiet of their home, and therefore, it would be unrealistic for the patient to expect this.

The second example of counseling on realistic benefits is derived from the observation that patients purchasing "new" hearing aids *expect* to hear as well as their normal-hearing friends. To combat this, the patient is asked, when communicating in noisy listening situations, to mentally "score" the percent of the conversation he has heard. The authors ask the patient to log the "score" in his head. Then the patient is counseled to ask his normal-hearing friend(s) what percent of their conversation he is understanding. The difference between the percent he understands and the percent the normal-hearing friend(s) understands will probably not be as large as the patient thinks. That is, even friends with normal hearing experience great difficulty in noisy environments, and he is not doing as well as our patient thinks he is. After this exercise, the patient typically has a better "feel" for the benefit he is achieving with his aids, and his expectations become more realistic. The authors go on to counsel that if the patient desires to achieve even greater benefit in noise, then he needs to pursue ALDs and be enrolled in an auditory rehabilitation program.

Directional Microphones

On the global issue of reduced aided performance in noise, significant gains over the past decade have been achieved via directional microphones. The authors believe there are two current technologies that can significantly improve the recognition of speech in noise for listeners with hearing loss: directional microphones and ALDs.

Countless articles have been published over the past decade supporting the advantages of directional microphones in significantly improving the recognition of speech in noise relative to performance with omnidirectional microphones. It is beyond the scope of this article to extensively cover this topic, but hearing aids have advanced to the point where more than two microphones can be placed in a hearing aid for even greater improvement in noise. In addition, the size of microphones has decreased sufficiently so that two microphones can now be placed in an in-the-canal (ITC) hearing aid. In addition, the presence of DSP allows for the real-time calibration of these microphones to provide maximum benefit at all times.

ALDs can provide even better performance in noise than directional microphones. In a two-site study, Lewis et al (2004) reported that an FM (frequency modulated) system coupled to the subject's hearing aids improved the signal-to-noise ratio (SNR) by an average of 14 to 16 dB relative to the performance with directional microphones. In addition, the use of binaural FM receivers, when compared to monaural FM performance, further improved the SNR by 2.5 to 2.7 dB.

FITTING HEARING LOSS WITH A RISING CONFIGURATION

As reported by Johnson and House (1979), approximately 71% of MD patients with hearing loss had a rising configuration with poorest hearing at 250–500 Hz. The remaining configurations were flat (20%), falling (6%), or trough shaped (3%). In addition, a patient may exhibit different audiometric configurations depending on the stage of MD. The PTA for the patients in the Johnson and House (1979) study were 26 dB HL or less (15%), 27–40 dB HL (20%), 41–55 dB HL (35%), 56–70 dB HL (20%), and 71 dB HL or greater (10%).

Providing a successful hearing aid fitting to a patient with a hearing loss with a rising configuration (i.e., poorer hearing in the low frequencies with progressively better hearing as frequency increases) can present some challenges. First, as a result of the better hearing in the high frequencies, the patient may not even be aware that a hearing loss is present. This is especially true if the opposite ear is normal. As a result of this first factor, often these patients are not well motivated toward amplification because they do not believe that a problem is present. As all experienced clinicians are aware, an unmotivated patient is *not* a ideal candidate for amplification. The authors learned years ago not to pursue amplification if there is an inclination of the lack of motivation toward amplification. Also, as will be described in the subsequent paragraphs, significant difficulties may arise when audiologists attempt to provide a frequency-gain response that is proportional to the magnitude of hearing loss.

Most often audiologists apply an amount of gain that is prescribed for the magnitude of hearing loss. Thus, in the typical MD patient, the likely strategy would be to apply greater gain in the lower frequencies and less gain in the mid- and high frequencies. Thus, patients with low-frequency hearing loss (LFHL) would usually be provided a hearing aid in which the frequency-gain response would be low-pass. It has been suggested (Studebaker et al, 1999) that applying excessive gain/output to the low frequencies may serve to mask the audibility of the mid- and high-frequency sounds (i.e., upward spread of masking), which may result in decreased intelligibility of speech in both quiet and noise (i.e., excessive amplification of the low-frequency ambient noise). Also, this type of fitting strategy may require an earmold/hearing aid case with a closed or narrow vent to provide the magnitude of prescribed gain/output. The use of a closed or narrow vent may lead to patient reports/complaints of the OE. Also, the use of a small vent in patients with good high-frequency hearing may prevent the direct entrance of the high-frequency components of the signal that may further contribute to poor speech recognition.

Schum and Collins (1992) evaluated four fitting strategies for six subjects with LFHL. The first strategy was low-pass (LP) where the greatest gain (half the hearing loss) was in the low frequencies with progressively less gain in the high frequencies. This is the frequency-gain response that would typically be fit by most audiologists. The second strategy was high-pass (HP) where little gain was provided in the low frequencies and greater gain was provided in the high frequencies where hearing improved and in the adjacent frequency region where hearing was normal. The third strategy was broadband (BB) where gain was provided throughout the frequency response, but the greatest amount of gain was provided in the midfrequencies. The last strategy was K-Bass that provided gain equal to half the hearing loss in the region of hearing loss with speech energy outside this range transmitted without attenuation (i.e., as if fit with an open earmold). The investigators utilized the California Consonant Test (CCT, Owens and Schubert 1977) and male connected discourse presented at +5 dB SNR for the four fitting strategies. For the connected discourse, the BB response received the highest subjective rating for four of the six subjects. One subject rated the K-Bass as the best, and one subject rated the HP as the best. None of the subjects rated the LP as their preferred response, and in fact this was given the lowest rating by four of the six subjects. For the objective results, the alternative fitting strategies reported CCT scores that were significantly better than the CCT score for the LP condition. The BB response received the highest score for three subjects; the K-Bass provided the highest score for one subject; and the HP strategy provided the highest score for two subjects. Again, the poorest objective scores were reported for the LP strategy for all six subjects.

A study by Collins et al (1985), cited in Schum and Collins (1992), goes even further to present their case for *not* using an LP fitting strategy for patients with LFHL. These investigators found that 12 subjects with LFHL were fit unsuccessfully using the LP strategy with commercially available hearing aids based on their statements of satisfaction and/or benefit with their current aids. These subjects were alternately fit with the HP and BB strategies using commercially available hearing aids. These investigators reported that hearing aids with the HP or BB frequency-gain response resulted in higher consonant discrimination and subjective preference by the 12 listeners in comparison to the LP frequency-gain response. It appears, from at least the results from these two studies, that patients with LFHL will perform better with alternative strategies to the "typical" LP strategy most probably utilized by many audiologists when faced with patients demonstrating LFHL.

FITTING REDUCED DYNAMIC RANGE

One of the reported outcomes of MD (Johnson and House, 1979) is reduced DR with increased recruitment. In addition, because of the fluctuating nature of MD, it is safe to assume that each fluctuation in hearing levels probably results in an equally fluctuating DR. Thus, with an MD patient, it is best to "view" each audiogram as a different patient for which the audiologist would fit a different frequency-gain/output response. The audiologist then could program a different frequency-gain/output response for each fluctuation and place the appropriate response into a different program of the hearing aid.

The authors believe it is important to measure the *individual* loudness discomfort level (LDL) and *not* rely on predicted LDL based on averaged group. This procedure is discussed in great detail in Valente et al (1997a) and Valente and Valente (2001), and the rationale for measuring individual LDLs is based on the following premises:

1. Intersubject variability in LDL (in dB HL or SPL) for the same hearing level can be 30 dB or more (Kamm et al, 1978; Dillon et al, 1984; Hawkins et al, 1987; Pascoe, 1988; Valente et al, 1994; Valente et al, 1997b; Bentler and Cooley, 2001). Thus, the authors are not comfortable in the accuracy of predicting individual LDL based on averaged group data.
2. Because of this large intersubject variability, many national and international hearing aid fitting guidelines recommend the individual measurement of LDL (British Society of Audiology, 1987; ASHA, 1998; College of Audiologists and Speech-Language Pathologists of Ontario, 2000; American Academy of Audiology, 2004).
3. Clinically, most manufacturer fitting software modules and real ear analyzers use the mean data reported by Pascoe (1988) to predict the LDL when the audiologist enters the patient's audiometric threshold. Unfortunately, in the authors' opinion, the categorical loudness scale used by Pascoe (1988) to measure LDL was based on the subject reporting when the intensity of the pulsed pure-tone signal (500, 1000, 2000, and 4000 Hz) was "Too Loud!" The authors use a procedure (Valente et al, 1997a; Valente and Valente, 2001) where the LDL (in dB HL and dB SPL) is the level where the patient reports the continuous pure-tone signal (500, 1000, 2000, 3000, and 4000 Hz) is "Loud, but OK." In a small clinical study performed several years ago, the first author found that the mean difference in LDL between "Too Loud" and "Loud, but OK" was 10–15 dB depending on the magnitude of hearing loss (i.e., difference became greater as hearing loss increased). Thus, the audiologists can target the output to be approximately 10–15 dB lower than would have been set if using the predicted target for output based on the Pascoe (1988) data.
4. Munro and Patel (1998) reported significantly reduced patient complaints of intolerance to loud sounds in the "real-world" when the output of the hearing aid was adjusted to the *measured* real-ear LDL. Their results revealed that the more the output exceeded the measured LDL, the more the subject reported loudness tolerance problems to environmental sounds of long duration. This study supports the external validity of clinically measuring the individual LDL.
5. Jenstad et al (2003) reported the results of a questionnaire from 320 "expert" audiologists. Of the 40 most frequent patient complaint descriptors reported by these experts, the highest response (797 occurrences) were patients reporting that their hearing aids were "Too Loud!" The closest reported occurrence (497) was "whistling." Thus, it appears that the output of current hearing aids (linear or nonlinear) is set excessively high in many fittings.
6. The prescribed output, based on the individually measured LDL in dB SPL near the tympanic membrane

may need to be reduced even further due to binaural summation of loudness (approximately 6 dB in each ear; Bentler and Nelson, 2001) and power/channel summation (Dillon, 2001; Kuk and Ludvigsen, 2003). This latter correction is relatively recent and is related to the number of channels of compression in current hearing aids. The greater the number of channels of compression, the greater the need to reduce the target created by the measured LDL. For example, Dillon (2001) suggested a 5 dB reduction in the targeted SSPL90 for a two-channel hearing aid and 10 dB for a five-channel hearing aid. Kuk and Ludvigsen (2003) reported the measured output of a 15-channel hearing aid was approximately 10 dB greater than the measured output of a one-channel hearing aid and 5 dB higher than two- and three-channel hearing aids after each aid was matched in output to the NAL-R (National Acoustic Laboratories—Revised) (Byrne and Dillon, 1986) target using a pure-tone sweep at 60 dB SPL.

As mentioned earlier, multichannel compression is currently available using a wide variety of compression strategies alone or in combination with each other. One popular compression strategy is wide dynamic range compression (WDRC) with either treble increase for low levels (TILL) or base increase for low levels (BILL). For the MD patient, a case could made for BILL processing because with this strategy the low-frequency segment of the frequency response increases automatically for soft input signals and, alternatively, decreases automatically as the input level increases. In addition, the high-frequency region would typically apply linear signal processing. In many current hearing aids the audiologist can program the crossover frequency (Cf) to divide the frequency range into the low- and high-frequency channel to apply the different compression strategy (i.e., BILL in the low-frequency channel and linear in the high-frequency channel). In the case of the MD patient, the Cf would usually be programmed at the frequency where the hearing loss begins to improve (i.e., rising configuration usually found in MD patients). The Oticon DigiFocus is an example of a hearing aid providing this type of compression, but many other current hearing aids could be programmed to provide BILL processing.

CONCLUSION

There are a multitude of options available to audiologists to successfully fit hearing aids to MD patients. This article outlined some of the problems often seen in patients with MD and offered suggestions on how current hearing aid technology, fitting strategies, and patient counseling could be used to improve the comfort and intelligibility of speech for these patients. These suggestions include:

1. Advantages offered by the features provided by DSP.
2. Using DMs and ALDs to improve speech recognition in noise
3. Using wireless CROS and BICROS as well as the BAHA for patients with unilateral or asymmetrical hearing loss.
4. Providing suggestions on counseling patients on the realistic expectations from amplification in noisy listening situations and for those with poor speech recognition.
5. Using multiple programs for greater benefit for patients with fluctuating hearing loss.
6. Offering suggestions on programming the frequency-gain/output response for patients with a rising configuration.

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