Prescription of Hearing Aids using Auditory Steady State Responses (ASSR)

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Abstract

Hearing aid prescription involves setting the gain at different frequencies and other parameters including compression ratio and compression knee-point. Verification of hearing aid can be done using subjective techniques such as functional gain and objective techniques such insertion gain or electrophysiological tests. In the present study, intensity-amplitude functions were obtained from measures of loudness growth using Auditory Steady State Responses (ASSR). Using this, the gain and compression ratio of the hearing aid were estimated. The relationship between amplitude and intensity of the ASSR was compared in a group of adults having normal hearing with that adults having moderate and moderately-severe sensorineural hearing loss. This was done to propose a method to derive information on hearing aid characteristics from the amplitude- intensity function of the ASSR. This procedure enabled determination of some basic properties of hearing aids, such as average gain, compression ratio. The study also aimed at comparing the gain and compression ratio estimated by ASSR with that predicted by NAL-NL1 and FIG6 prescriptive procedures. From the results of the study it can be inferred that, the gain prescribed by ASSR-PF can also be useful in prescribing hearing aid gain as it was comparable with other prescriptive formulae. Thus, the ASSR serves as an objective tool in verifying the hearing aid prescription process for difficult-to-test population such as infants, young children in whom reliable behavioural responses cannot be obtained.

Key words: gain, compression, intensity-amplitude function, prescriptive procedures.

Introduction

Hearing aid fitting follows three main steps. They are assessing hearing loss, prescribing an aid to compensate for this hearing loss and verifying that this aid provides adequate benefit (Scollie & Seewald, 2001). Each step has its own contribution in hearing aid fitting. Hearing assessment evaluates the hearing threshold, speech identification, maximum comfort levels (MCL) and loudness discomfort level (LDL) at different frequencies. Prescription sets the gain and other parameters including compression ratio and compression knee-point of a selected aid so that the average spectrum of speech sounds is amplified to levels within the range between the unaided thresholds and the loudness discomfort levels of an individual (Cornelisse, Gagné, & Seewald, 1991; Stelmachowicz, Mace, Kopun, & Carney, 1993; Byrne & Dillon, 1986; Cornelisse, Seewald, & Jamieson, 1995). Verification provides some measurement of how well the sounds are heard when the aid is used at its prescribed settings (Stelmachowicz, Kopun, Mace, Lewis, & Nittrouer, 1995).

Fitting hearing aids in adults and older children with hearing loss can be guided by subjective responses to amplified sounds (Picton, et al., 1998). One of the popular subjective measures for selection of a hearing aid is the 'functional gain'. The 'functional gain' a patient

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receives can be determined by obtaining the difference between the unaided and aided thresholds for a particular stimulus (Dillon, 2001). In the case of difficult-to-test population with hearing loss who are unable to provide behavioral responses, objective methods - such as real ear measures and electrophysiological measures - must be relied upon to guide the hearing aid fitting and verification process.

Over the years, data have begun to accumulate which suggest that the ASSR threshold estimates are reasonably accurate in predicting the behavioral thresholds. A number of investigators have reported that ASSR thresholds correlate well with behavioural thresholds. (Cone-Wesson, Dowell, Tomlin, Rance, & Ming, 2002). The amplitude of the ASSR can be used in the estimation of loudness growth function. This information can be used in setting the hearing aid parameters. The validity of using ASSR in hearing aid selection has been evaluated (Vanaja & Manjula, 2004; Damarla & Manjula, 2007) and it has been found that ASSR can be used in setting the gain of the hearing aid.

Apart from setting the gain of the hearing aid, the ASSR can also be used for setting the compression ratio of the hearing aid. The Auditory Steady State Response - Prescription Formula (ASSR-PF) enables determination of some of the basic properties of hearing aids, such as, gain across frequencies and compression characteristics based on the dynamic range of hearing (Zenker, Ferna´ndez, & Barajas, 2005). In this ASSR-PF procedure, the amplitude-intensity function of the ASSR can be used to derive the information on hearing aid characteristics such as gain and compression ratio. The setting of the gain and compression ratio is done by comparison of the amplitude-intensity function of the ASSR for the clients with hearing impairment with that of those with normal hearing.

Recent studies have proposed that assessment of auditory evoked potentials, and specifically ASSRs, could serve as useful tools in the fitting and verification of the hearing aids (Cone-Wesson, Parker, Swiderski, & Ricakrds, 2002; Picton et al., 1998; Zenker, Fernandez, & Barajas, 2006).

Need for the study

Fitting the hearing aid includes setting the gain and compression characteristics of the hearing aid depending on the hearing threshold and loudness growth of an individual. For this, ASSR can be used as an objective tool. It has been shown that the FG obtained through ASSR and that obtained through sound field audiometer were highly correlated (Vanaja & Manjula, 2004). Further, the FG obtained through ASSR and the IG were also well correlated (Damarla & Manjula, 2007). There are very few studies that have evaluated the usefulness of ASSR in setting the gain as well as compression parameters of the hearing aid (Zenker, Fernandez, & Barajas, 2005). Thus, the present study aims at evaluating the usefulness of the ASSR in setting the gain as well as the compression parameters of the hearing aid.

Objectives

The aims of the present study were

1. To estimate the gain of a hearing aid by the measurement of hearing threshold using ASSR.
2. To estimate the compression ratio of the hearing aid by the measurement of dynamic range, i.e., the difference between the uncomfortable level and the threshold, using ASSR.
3. To compare the gain obtained by ASSR and that estimated by NAL-NL1 and FIG6.
4. To compare the compression ratio obtained by ASSR and that estimated by NAL-NL1 and FIG6.

Method

The following method was adopted to investigate the aims of the study.

Participants

Eighty participants were included in the three groups. Their age ranged from 15 to 55 years, with a mean age of 31.2 years and standard deviation of 3.1 years. The participants were divided into three groups:

- Group I comprised of individuals (N=40) with normal hearing.
- Group II comprised of individuals (N=20) with moderate degree of flat sensorineural (SN) hearing loss in both the ears.
- Group III comprised of individuals (N=20) with moderately severe degree of flat sensorineural (SN) hearing loss in both the ears.

Instruments used

- A calibrated double channel diagnostic audiometer for pure tone audiometry and speech audiometry.
- A calibrated diagnostic immitance meter to confirm the normal middle ear function through tympanometry and acoustic reflex measurement.
- GSI Audera (version 2.6) to record the ASSR through insert earphones.

Procedure

The testing was carried out in a sound treated environment. Pure tone audiometric thresholds were obtained using modified Hughson - Westlake procedure (Carhart & Jerger, 1959). Speech audiometry was performed to establish the speech reception threshold, speech identification scores and uncomfortable level for speech. Immittance evaluation was carried out to ensure normal middle ear functioning. These measurements were carried out on each participant to ensure that the participants met the selection criteria.

The data were collected in two phases.

Phase I: Calculating the hearing aid parameters using NAL-NL1 and FIG6.
Phase II: Calculating the hearing aid parameters using ASSR-PF.

Phase I: Calculating the Hearing Aid Parameters using NAL-NL1 and FIG6

The gain for moderate level sounds (65 dB SPL) was calculated at 500 Hz, 1000 Hz, 2000 Hz, and 4000 Hz. For each participant, the gain for moderate level sounds at these four frequencies was computed manually, for both NAL-NL1 and FIG6 using the respective prescriptive formula. The compression ratio was calculated by feeding the audiogram information into the NOAH (3.0) software and simulating a double channel hearing aid with appropriate gain. The default values for the compression ratio at 500 Hz and 2000 Hz as prescribed by NAL-NL1 and FIG6 were noted.

Phase II: Calculating the hearing aid parameters using ASSR-PF

The participant was made to sit comfortably on a reclining chair. He/she was instructed to relax, close the eyes and sleep, if possible while recording the ASSR using the calibrated GSI Audera equipment. The site of electrode placement was prepared with skin preparing paste. Disc type silver coated electrodes were placed with conduction gel. The non-inverting electrode (+) was placed on high forehead (Fz), ground electrode was placed on non-test ear mastoid and the inverting electrode (-) was placed on the test ear mastoid. It was ensured that the impedance of each electrode was less than 5 k Ohms and that the inter-electrode impedance difference was less than 2 k Ohms. The ASSRs were recorded using the insert earphones. ASSR measurements were performed using high modulation frequency of 74, 81, 88, 95 Hz for 500, 1000, 2000 and 4000 Hz respectively, with an amplitude modulation rate of 100% and frequency modulation of 10%.

To find out the dynamic range through ASSR, the testing was initiated at the behavioural threshold level and the intensity was increased in 10 dB steps till the intensity level of UCL–5dB was reached. This was done separately for each of the four test frequencies, i.e., 500 Hz, 1000 Hz, 2000 Hz, and 4000 Hz. The amplitude level of the ASSR at each measurement was noted down for the participant.

For participants in Group I, the intensity - amplitude curve was obtained at the four different frequencies, i.e., 500 Hz, 1000 Hz, 2000 Hz and 4000 Hz. For participants in Group II and III, the gain at the four frequencies and the compression ratio at 500 and 2000 Hz were determined using the ASSR-PF formula. This procedure namely the Auditory Steady State Response-Prescription Formulae (ASSR-PF) enables determination of some basic parameters of hearing aids, such as dynamic range, frequency response, gain, compression factor, Input-Output function and Maximum Power Output (Zenker, Fernandez, & Barajas, 2005). In the present study, the gain at four frequencies and compression ratio at two frequencies using ASSR-PF were computed for each participant in Group II and Group III.

The ASSR-PF gave information about some critical parameters for fitting hearing aids. First, the hearing dynamic range established from the ASSR hearing threshold and loudness discomfort level; second, the hearing aid characteristics supposed to amplify the entire range of speech into the dynamic range of a particular hearing loss; third, the difference between the hearing loss and the lower limit of the speech dynamic range provided the amount of the gain required by the hearing aid; fourth, the compression factor determined by the degree of hearing loss relative to the long-term average speech spectrum (LTASS) based on the amplitude growth function of the electrophysiological Auditory Steady State Response of the participants.

The dynamic range, gain and compression ratio were obtained from the amplitude projection procedure (APP) as depicted in the Figure 1. The amplitude level function for the group of participants with normal hearing (Group I) was represented by the solid line curve and the amplitude level functions for the group of participants with moderate and moderately severe hearing impairment (Group II & III) were represented by dashed and dotted curves respectively.

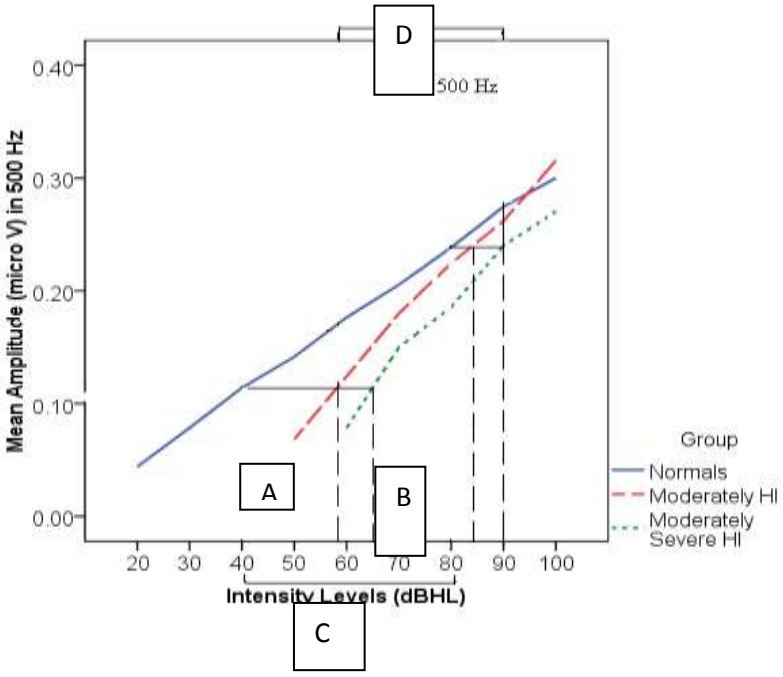

Fig. 1: The amplitude projection procedure (APP) for calculation of gain and compression ratio at 500 Hz.

The dynamic range of speech (40 to 80 dB) was projected upward from the abscissa to the normal amplitude intensity function for each of frequency. Then, the gain requirement is estimated as the difference between the point at which the dotted line (A or B) intersected the X-axis and the lower limit of the input dynamic range (i.e., 40 dB). The compression ratio is given by the ratio of output dynamic range of the participant to the input dynamic range.

From Figure 1, for the group with moderate hearing loss, the gain was calculated as the difference between the hearing loss (59 dB, A) and the lower limit of the LTASS (40 dB), or 59–40 = 19 dB. The compression ratio was calculated by the ratio of the normal speech dynamic range (80–40 = 40 dB, C) to the ratio of the dynamic range of the participant (85–59 = 24, D). Thus, the compression ratio was 40/24 = 1.6.

The gain at all the four frequencies obtained by NAL-NL1 prescriptive rule was compared with the gain at all the four frequencies obtained through Auditory Steady State Response-Prescriptive Formula (ASSR-PF). The compression ratio (CR) prescribed by NAL-NL1 was compared with the values obtained by ASSR-PF for all the participants at 500 Hz and 2000 Hz. The same procedure was repeated for FIG6 also. This was done in order to compare ASSR based hearing aid prescription with that of NAL-NL1 and FIG6 prescription in terms of gain and compression ratio.

Results and Discussion

The data collected were statistically analyzed, using statistical package for social sciences (SPSS). These results are being discussed below.

The target gain prescribed by ASSR-PF, NAL-NL1 and FIG6 were within 6 dB of each other for the moderate hearing loss group (Group II). The results of the present study, for moderate hearing loss (Group II), indicated that there was a significant difference between the gain prescribed by ASSR-PF and NAL-NL1 at 500 Hz. At 1000 Hz and at 2000 Hz, there was a significant difference between ASSR-PF and FIG6. At 4000 Hz, there was no significant difference in the amount of gain prescribed between any of the three prescriptive formulae.

The target gain prescribed by ASSR-PF, NAL-NL1 and FIG6 were within 14.3 dB of each other for the moderately severe hearing loss group (Group III). The results of the present study, in moderately severe hearing loss (Group III), indicated that there was a significant difference between the gain prescribed by ASSR-PF and NAL-NL1 at 500 Hz. At 1000 Hz and 2000 Hz, the results indicated that there was no significant difference between NAL-NL1, FIG6 and ASSR-PF. At 4000 Hz, there was a significant difference between ASSR-PF and FIG6.

In Group II, the results indicated that there was a significant difference between the compression ratio values at 500 Hz and 2000 Hz. In Group III, Bonferroni multiple comparison tests indicated that there was no significant difference between the compression ratio values obtained by ASSR-PF and NAL-NL1 at 500 Hz. In Group III, the results indicated that there was a significant difference between the compression ratios at 2000 Hz prescribed by ASSR-PF, NAL-NL1 and FIG6. The gain and compression ratio for Groups I, II and III are discussed below.

I. Moderate hearing loss (Group I)

A. Gain

The target gain prescribed by ASSR-PF, NAL-NL1 and FIG6 were within 10.9 dB of each other. Zenker, Fernandez, and Barajas (2005) in their study, reported that there was a significant difference between the gain prescribed by ASSR-PF and NAL-RP, POGO, and Berger formulae. The results of the present study indicate that there was a significant difference between the gain prescribed by ASSR-PF and NAL-NL1 at 500 Hz only. ASSR – PF provided more gain than NAL-NL1. Picton (2003) has reported that this can be because the difference between the physiological threshold and behavioural threshold is higher at low frequencies. Here, the ASSR over estimates the threshold at 500 Hz and this will lead to increase in the amount of gain at that frequency. To overcome this, a correction factor can be incorporated in the present ASSR-PF to obtain the better estimation of gain at 500 Hz.

Dillon (2001) reported that the gain prescribed by NAL-NL1 is relatively lower at 500 Hz when compared to the other prescriptive formulae such as DSL i/o, FIG6 and IHAFF. As the NAL-NL1 formula tends to maximize the speech intelligibility, the low frequency parts of the speech which are more intense and less important than the high-frequency parts, i.e., relatively little low-frequency gain is required to maximize contribution to the Speech Intelligibility Index (SII) at the low frequencies. As the other procedures tend to normalize the loudness, they do not reduce the gain because they attempt to place speech at each frequency at the level needed to give normal loudness for that frequency.

The gain obtained at 1000 Hz, 2000 Hz and 4000 Hz was not significantly different between ASSR-PF and NAL-NL1, although the gain prescribed by NAL-NL1 was higher than that of ASSR-PF. As the ASSR-PF formula is based on the dynamic range of the LTASS. It gives more emphasis to the speech frequencies. The underlying rationale of NAL-NL1 prescription procedure is to maximize the speech intelligibility, subject to the overall loudness of speech at any level being more than that perceived by a person with normal hearing.

The gain obtained by ASSR-PF and FIG6 was not significantly different at 500 Hz and 4000 Hz although ASSR-PF prescribed higher gain. This may be attributed to the fact that FIG6 procedure prescribes a flat frequency response, for all input levels, for a flat audiogram. In the present study also, the participants had a flat configuration of audiogram.

The gain obtained by ASSR-PF and FIG6 was significantly different at 1000 Hz and 2000 Hz. At these frequencies, ASSP-PF prescribed significantly higher gain than FIG6. This may be because the FIG6 procedure specifies the gain to normalize loudness, whereas, the ASSR-PF prescribes the gain based on the long-term average speech spectrum, (LTASS).

B. Compression ratio

The compression ratio obtained by ASSR-PF was significantly lower than NAL-NL1 and FIG6 at 500 Hz and 2000 Hz. This may be attributed to the fact that ASSR-PF prescription is based on intensity-amplitude function wherein at higher intensities the amplitude of ASSR in individuals with hearing impairment equals that of individuals with normal hearing leading to reduction in the dynamic range and thus the compression ratio.

II. Moderately severe hearing loss (Group III)

A. Gain

As in the group with moderate hearing loss, the results in this group also indicated that there was a significant difference between the gain of ASSR-PF and NAL-NL1 at 500 Hz. ASSR-PF provided significantly higher gain than NAL-NL1. Picton (2003) reported that this can be because of the difference between the physiological threshold and behavioural threshold is higher. Thus, the ASSR over estimates the threshold at 500 Hz. This will lead to increase in the amount of gain at that frequency prescribed by ASSR-PF than that by NAL-NL1. To overcome this, a correction factor can be incorporated in the present ASSR-PF to get a lower better estimation of gain at 500 Hz, as the low frequency components of speech are louder.

The gain obtained at 1000 Hz, 2000 Hz and 4000 Hz was not significantly different between ASSR-PF and NAL-NL1. Although ASSR-PF and NAL-NL1 formulae are based on the dynamic range of the LTASS, the NAL-NL1 prescribed gain was not significantly higher than that of ASSR-PF.

The gain obtained by ASSR-PF and FIG6 was significantly different at 4000 Hz. As FIG6 is based on the rationale that high-frequency components contribute more to speech intelligibility, it provided significantly higher gain than ASSR-PF.

The FIG6 procedure specifies the gain to normalize loudness, and it is based on average loudness data that relates equal-loudness and threshold curves. Whereas, the ASSR-PF prescribes the gain based on the long-term average speech spectrum.

B. Compression ratio

The compression ratio prescribed by ASSR-PF is significantly lower than that by FIG6 and NAL-NL1 at 500 Hz. Byrne, Dillon, Ching, Katsch, and Keidser (2001) have reported that with the increase in degree of hearing loss, the FIG6 prescribes higher compression ratio than the other prescriptive procedures. However, Dillon (2001) reported that with the increase in degree of hearing loss, the compression ratio should be lesser to make the input-output function more linear.

The compression ratio prescribed by ASSR-PF is significantly lower than that by FIG6 and NAL-NL1 at 2000 Hz. This may be because; the NAL-NL1 tends to use less compression than the other procedures such as DSL-i/o, FIG6 and IHAFF which differ considerably (Byrne, et al., 2001).

Byrne, et al., (2001) reported that for the present, such prescriptions must be based mainly on logic as there is very limited evidence on which compression thresholds (CTs) and ratios (CRs) are best. It is observed that FIG6 procedure prescribes higher compression ratio than other procedures. The FIG6 procedure prescribes more compression at high frequencies.

However, a high degree of compression could result in unacceptable sound quality. There is little information on which to judge the amount of compression needed to maximize comfort or the amount of compression that can be used before sound quality is perceived as being degraded (Moore, et al., 1998). More information can be obtained if done on subjects to see if the prescribed compression ratios are right or to check the quality of speech with different compression ratios.

Conclusions

Several studies have reported that the auditory steady state responses could be used to estimate the frequency specific auditory sensitivity. These studies have reported that there is a good correlation between behavioural thresholds and the thresholds estimated from ASSR. Electrophysiological tests like ASSR can assist in hearing aid prescription since they can measure frequency specific auditory thresholds. Thus, the present study aimed at investigating the gain and compression ratio obtained through ASSR based prescriptive formula (ASSR-PF) proposed by Zenker, Fernandez, and Barajas, (2005). The study also aimed at comparing it with the gain and compression ratio obtained through NAL-NL1 and FIG6 prescriptive procedures.

1. In Group II with moderate hearing loss, the following observations were noted for the gain prescribed by ASSR-PF, NAL-NL1 and FIG6.
    - There was a significant difference in gain between ASSR-PF and NAL-NL1 at 500 Hz ($p < 0.001$), the mean gain provided by ASSR-PF was 4 dB higher than NAL-NL1.
    - There was no significant difference in gain between ASSR-PF and NAL-NL1 at 1000 Hz, 2000 Hz and 4000 Hz ($p > 0.05$).
    - There was a significant difference in gain between ASSR-PF and FIG6 at 1000 Hz and 2000 Hz ($p < 0.001$). The mean gain provided by ASSR-PF was 4.1 dB, and 3.8 dB higher than FIG6 at 1000 Hz and 2000 Hz respectively.
    - There was no significant difference in gain between ASSR-PF and FIG6 at 500 Hz and 4000 Hz ($p > 0.05$).

2. In Group II with moderate hearing loss, the following findings were observed for the compression ratio prescribed by ASSR-PF, NAL-NL1 and FIG6.
    - There was, a significant difference in the prescription of compression ratio by ASSR-PF, NAL-NL1 and FIG6 ($p < 0.001$) at 500 Hz and 2000 Hz. The mean compression ratio prescribed by FIG6 was 0.6 and 0.1 higher than ASSR-PF and NAL-NL1 respectively.

3. In Group III with moderately severe hearing loss, the following findings for the gain prescribed by ASSR-PF, NAL-NL1 and FIG6 were observed.
    - There was no significant difference in gain between ASSR-PF and NAL-NL1 at 1000 Hz, 2000 Hz and 4000 Hz ($p > 0.05$).
    - There was a significant difference in gain between ASSR-PF and NAL-NL1 at 500 Hz ($p < 0.001$), the mean gain prescribed by ASSR-PF was 3.9 dB higher than NAL-NL1.
    - There was a significant difference in gain between ASSR-PF and FIG6 at 4000 Hz ($p < 0.001$), the mean gain prescribed by FIG6 was 4.5 dB higher than ASSR-PF.
    - There was no significant difference in gain between ASSR-PF and FIG6 at 500 Hz, 1000 Hz and 2000 Hz ($p > 0.05$).

4. In Group III with moderately severe hearing loss, the following findings were noted for the compression ratio prescribed by ASSR-PF, NAL-NL1 and FIG6.
    - There was no significant difference in the prescription of compression ratio by ASSR-PF and NAL-NL1 at 500 Hz, ($p < 0.001$), however, there was significant difference in the prescription of compression ratio by ASSR-PF and FIG6 at 500 Hz ($p > 0.05$), and compression ratio prescribed by FIG6 was 1.1 dB higher than ASSR-PF.
    - There was a significant difference in the prescription of compression ratio by ASSR-PF, NAL-NL1 and FIG6 at 2000 Hz ($p < 0.001$), FIG6 prescribed 1.1 dB and 0.8 higher than ASSR-PF and NAL-NL1 respectively.

From the results of the study it can be inferred that, the gain prescribed by ASSR-PF can also be useful in prescribing hearing aid gain as it was comparable to NAL-NL1, except at 500 Hz. At 500 Hz a correction factor is required for ASSR-PF to be more efficient for hearing aid prescription. Thus, ASSR serves as an objective tool in verifying the hearing aid prescription process for difficult-to-test population such as infants, young children in whom reliable behavioural responses cannot be obtained.

Clinical implications

Use of ASSR, an objective measure, for prescribing gain and compression ratio for individuals with hearing loss will be highly useful. This is especially true for prescribing hearing aid for the difficult-to-test populations.

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