Threshold Measurements by Self-Fitting Hearing Aids: Feasibility and Challenges

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Abstract

A self-fitting, self-contained hearing aid is a device that can be managed entirely by the user, without assistance from a hearing health care professional or the need for special equipment. A key component of such a device is an automated audiometer that will enable the user to self-administer measurements of in situ thresholds, which the hearing aid will use to prescribe a baseline setting for the wearer. The success of the device therefore depends on the validity and reliability of in situ threshold measurements and automatically measured thresholds. To produce a complete and self-contained device, the self-fitting hearing aid will also enable identification of audiograms that are contraindicated of hearing aid usage. The feasibility and challenges of achieving these characteristics are explored and discussed. While the overall concept seems feasible, several challenges were identified that need thorough investigation and/or development. These include the use of instructions to self-manage hearing aid insertion and in situ threshold measurements, selection of an appropriate transducer and instant-fit tip that will allow measurements of a wide range of threshold levels, control of ambient noise during threshold measurements, and self-manageable procedures that enable identification of such audiogram characteristics as asymmetry and conductive hearing loss.

Keywords

amplification, automated audiometry, hearing aid, in situ audiometry, self-fitting

Background

Over the years, many investigations have focused on the low uptake and usage of hearing aids among populations who have reliable access to audiological services (e.g., Knudsen, Öberg, Nielsen, Naylor, & Kramer, 2010). The aim of such studies is generally to obtain a better understanding of the barriers to hearing aid usage, so that approaches to facilitate greater uptake of devices and improved outcomes can be developed. However, hearing aid uptake is much lower, or significantly delayed, among large populations who have no reliable access to audiological services. This scenario applies mostly to people living in developing countries but also applies to populations living remotely in large developed countries, such as Australia, Canada, and the United States. In developing countries the situation is attributed to a combination of the cost of hearing aids relative to household income and the lack of a professional audiological infrastructure (e.g., McPherson, 2011). In developed countries, access and inconvenience are the more likely factors preventing hearing aid uptake among candidates living in remote locations. Given the economic impact a hearing loss has on society (Access Economics, 2006), the global shortage of qualified hearing health care professionals, and the increase in the population of adults above the age of 65, there is clearly a need for alternative options and/or service

delivery models to reach populations with limited access to the current service model.

One approach to making hearing aids more accessible to more people has been to make so-called “self-fitting” devices available for purchase via the Internet or other nontraditional channels. A recent review of current devices falling into this category revealed that they all require either a known audiogram, which requires a visit to a hearing health care professional, and/or access to a computer or other specific equipment to obtain and fit the devices, sometimes using rather sophisticated software (see Convery, Keidser, Dillon, & Hartley, 2011, for more details). Both factors are likely to prevent these devices from becoming a successful solution in developing countries, and the need for seeing a clinician in person is not ideal for people living remotely in developed countries. Therefore, such alternative devices have, to date, mainly had success as a low-cost option for people in developed countries, of whom many have ready access to audiological

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services. As a result, there have been several cases in which self-fitting devices have been brought to a professional with a request for help with fitting, fine-tuning, or management. Such a scenario places the clinician in a difficult situation if the clinician typically bundles the cost of hearing aids and associated services, and/or if the client is eligible for a financial assistance program that does not support the purchased device. Consequently, there seems to be a need for a device that is not only completely self-fitting but also self-contained. That is, there is a need for a device that can be fitted entirely by the user with no assistance from a hearing health care professional or access to equipment other than the device itself, while producing the outcomes consistent with those currently achieved with professionally fitted hearing aids.

The concept of a self-fitting, self-contained hearing aid has been introduced in Convery et al. (2011). Based on a behind-the-ear (BTE) hearing aid body attached to an instant-fit tip, the concept assumes an onboard prescription procedure that uses hearing threshold levels, measured automatically and in situ with an on-board signal generator, as input to set the hearing aid parameters. If equipped with a training algorithm, the settings can be further fine-tuned by the user by adjusting the device settings in various environments until the device has learned to automatically adapt to the user's preferred settings (Dillon et al., 2006). If changes occur to the threshold levels or preferences over time, the aid can be readjusted by repeating the threshold measurements, or retraining the device.

In any hearing aid fitting, whether performed by a professional or by the hearing aid user, it is important to start with an appropriate baseline response, even if the user can subsequently train the device to apply more preferred gain settings in different environments. This is partly because the first impression of amplification could influence the continuous use of the device, and partly because the baseline response has been found to have a significant influence on the trained response (Dreschler, Keidser, Convery, & Dillon, 2008; Keidser, Dillon, & Convery, 2008; Mueller, Hornsby, & Weber, 2008). The baseline response is commonly achieved using a prescription procedure, which typically constitutes a formula that calculates frequency-specific gain using the person's hearing threshold levels (audiogram) as input. Clinically, the audiogram is further used to identify such characteristics as threshold asymmetry and the presence of a conductive component that may be associated with medically or surgically treatable hearing loss conditions. These can range from comparatively straightforward issues such as impacted wax to acoustic neuromas. Consequently, the audiogram provides important information for the guidance and execution of successful hearing rehabilitation. To ensure valid and reliable threshold measurements in the clinic, calibrated equipment is used and standardized measurement procedures followed. This article explores the potential for and challenges of achieving valid and reliable threshold data

with a self-fitting hearing aid without compromising those requiring medical assistance and/or alternative treatments.

Audiometry and Self-Fitting Hearing Aids

In the self-fitting hearing aid, threshold levels would be measured in situ; that is, through the actual hearing instrument and coupling that the hearing aid wearer will be fitted with, using an onboard signal generator to present pure tones, and an automated procedure to adaptively vary stimulus level and frequency. Referring to a set of instructions, the automated in situ audiometry process is envisaged to be activated by having the user press an onboard button, which also serves as the response button. By enabling threshold measurements only when the button is pushed down for an extended period, for example, 5 s, accidental in situ measurements should be largely avoided.

For some time, modern hearing instruments have been equipped with signal generators. Mostly, these are used to alert hearing aid wearers about low batteries, and to guide them through program and volume changes. For a small, but increasing, number of instruments, software is provided by the manufacturer that enables clinicians to use the onboard generators to measure threshold levels in situ (e.g., Ludvigsen & Tøpholm, 1997). However, to date, no hearing instrument exists in which automated in situ measurements are fully integrated within the device and can be performed independently by the user, nor has anyone yet investigated the reliability and validity of in situ thresholds measured automatically by the user through a hearing aid. Specific to the self-fitting hearing aid, it is of interest if valid and reliable in situ thresholds can be obtained if coupling the hearing aid to an instant-fit tip, which would be more likely to introduce low-frequency leakage than carefully placed earphones or customized earmolds with the vent temporarily blocked. Of further interest is whether an algorithm could be designed, using a more sophisticated decision-making process for changing level and step size, that produces automatically measured thresholds that are more reliable than those measured manually. Finally, being able to identify medical contraindications to hearing aid fittings would make the self-fitting hearing aid a more complete solution. These issues are addressed below.

In Situ Audiometry

Feasibility. Early investigations into in situ audiometry suggested it could provide threshold data that were as valid and reliable as conventionally measured threshold data (Smith-Olinde, Nicholson, Chivers, & Highly, 2006; Winter & Kuk, 1998). Both studies obtained in situ thresholds using Widex's Sensogram program, which generates pulsed FM tones (Ludvigsen & Tøpholm, 1997), and Widex behind-the-ear (BTE) instruments. However, the difference in threshold

levels measured on 14 children in Winter & Kuk (1998) was not analyzed in detail, and the data of Smith-Olinde et al. (2006) were limited to normal-hearing listeners. More recently, DiGiovanni and Pratt (2010) compared thresholds measured on both normal-hearing and hearing-impaired listeners conventionally and in situ using Widex's Sensogram program and Inteo BTE hearing aids coupled to an ER-3A earphone tip. They found a significant difference in thresholds for both normal-hearing and hearing-impaired listeners at 500, 1000, and 2000 Hz, which averaged 6 to 9 dB for the hearing-impaired listeners. Measurements were obtained and presented in dB HL, and while the audiometer was calibrated according to standards, there is no mention of calibration of the hearing aid transducer with the ER-3A earphone tip. It is possible that the discrepancy between thresholds could be explained by differences in dB SPL produced by the two transducers for a given dB HL value.

To obtain a better understanding of the reliability and validity of thresholds measured in situ, especially when coupling the hearing instrument to the ear via instant-fit tips, O'Brien, Keidser, Yeend, Hartley, and Dillon (2010) conducted a study on 24 hearing-impaired listeners. Participants had their hearing threshold levels measured twice through insert earphones using conventional audiometry, and in situ using a Siemens BTE instrument coupled to a closed and an open instant-fit tip. The real-ear-to-dial difference (REDD) was also obtained on each individual to enable conversion of the threshold levels from dB HL to dB SPL. For consistency, all measurements were obtained manually using a Matlab program to drive the transducers. The transducers were both calibrated in a 2 cc coupler according to ISO 389-2 (International Organization for Standardization [ISO], 1994).

This study found significant differences between dB HL thresholds at frequencies up to and including 1500 Hz that were consistent with low-frequency leakage from the less occlusive instant-fit tips. At 250 Hz, the average difference amounted to 30 dB for the open tip and 10 dB for the closed tip. When adding the individually measured REDD values to the dB HL threshold data, the average threshold levels expressed in dB SPL at the eardrum were within 1.5 dB, except in two cases where the difference between two threshold levels equaled 2 and 2.5 dB. In agreement with the earlier studies, O'Brien et al. (2010) found that the in situ threshold measurements were at least as reliable as those obtained conventionally. Overall, the current studies on in situ audiometry confirm the feasibility of measuring threshold in situ through a hearing instrument coupled to various instant-fit tips although ensuring valid and reliable data for an individual is not without its challenges.

Challenges. Apart from reducing the need for special equipment, an advantage of measuring hearing threshold levels in situ is that any error in the hearing threshold caused by the coupling of the transducer to the individual is partly offset by opposite error in the gain provided by the hearing aid, which makes use of this same transducer and coupling.

On the other hand, the same two factors, the hearing instrument transducer and coupling, will impose greater limitations on the range of threshold levels that can be measured with the instrument relative to those measurable with a clinical audiometer. In addition to the maximum output of the transducer, which determines the highest presentation level achievable across the entire frequency range, a narrow tube diameter can reduce the upper limit by up to 9 dB at high frequencies, while leakage from vents and open molds can reduce the upper limit by up to 30 dB at 250 Hz, 25 dB at 500 Hz, and 10 dB at 1000 Hz. It is also an inherent characteristic of hearing aid transducers that the higher the output levels, the greater the likelihood that lower level tones will be affected by transducer noise. Consequently, different transducers, and hence different hearing instruments, are essentially required for measuring different degrees of hearing loss, a fact that is a challenge for the self-fitting hearing aid as in most cases, the audiogram would not be known at the time of purchase. It would, therefore, be desirable if the self-fitting hearing aid had an inbuilt routine that could notify the user if the hearing loss is too mild or severe to benefit from the device, or deactivates the self-fitting process.

Ambient noise is a potential hazard for threshold measurements, especially if the hearing aid is coupled to the ear via an open instant-fit tip. The instructions for how to self-administer the audiometric measurements would naturally advise the wearer to go to a quiet room. Furthermore, it may be possible to use the microphone of the instrument to measure the level of the ambient noise and to measure its spectrum, and to present a warning to the wearer if the room is considered too noisy for valid threshold measurements. As the acceptable noise levels would depend directly on the user's degree of hearing loss, the preferred implementation would be one that alerts the wearer only when test levels are actually masked by room noise. This criterion could be further refined by only interrupting the threshold measurements if there is interference from ambient noise at more frequencies than are needed to prescribe an appropriate baseline setting.

Ensuring proper calibration of the transducer of the hearing instrument would be the responsibility of the manufacturer. As the data from O'Brien et al. (2010) suggest, this is not a simple matter if the self-fitting hearing aid comes with different options for coupling the device to the ear. This is because to reach valid thresholds in dB HL, the measured in situ thresholds in dB HL must first be converted to dB SPL using average REDD values appropriate to the selected instant-fit tip and hearing aid transducer to compensate for the expected low-frequency leakage. To determine the reliability of in situ thresholds if average REDD values were applied, O'Brien et al. (2010) examined the interparticipant variability of the REDD values. Figure 1 shows from that study the standard deviation values of the REDD measurements obtained with each transducer (insert earphones or hearing instrument) and coupling (foam ear tip or closed or

Figure 1. The average REDD standard deviation values measured under three conditions: conventionally through insert earphones (full line), in situ with the hearing instrument coupled to a closed instant-fit tip (broken line), and in situ with the hearing instrument coupled to an open instant-fit tip (dotted line). In addition, open and closed symbols show the REDD variability measured with supra-aural headphones and insert earphones, respectively, by Hawkins et al., 1990 (triangle), Valente et al., 1994 (circle), and Saunders & Morgan, 2003 (square).

open instant-fit tips). On balance across frequencies, the standard deviation values measured conventionally with the insert earphones and in situ with the open instant-fit tip were similar. The standard deviation values measured in situ with the closed instant-fit tip was, in comparison, much higher at 250 and 500 Hz. An investigation into this, including a comparison of the true interparticipant standard deviations with the intraparticipant standard deviations of the REDD measurements, revealed that the variation at the very low frequencies was due to an inconsistent seal achieved with the closed tip, both between participants and between appointments on the same individual. Figure 1 also shows the interparticipant standard deviation values for REDD measurements obtained conventionally through supra-aural headphones and insert earphones (Hawkins, Cooper, & Thompson, 1990; Saunders & Morgan, 2003; Valente, Potts, Valente, Vass, & Goebel, 1994). Generally, except for the in situ measurements with closed instant-fit tips at 250 Hz, the reliability of the in situ measurements is better than those obtained with supra-aural headphones, especially at frequencies above 2000 Hz. Measurements obtained in situ with the open instant-fit tips are at least as precise as those obtained with insert earphones. Overall, apart from threshold measurements at 250 Hz with a closed instant-fit tip, the use of average transducer- and coupling-specific REDD values, which would be required with a self-fitting hearing aid, should maintain validity although this needs to be properly verified. The compromise between an open tip, which yields more reliable threshold data but is susceptible to ambient noise, and a closed tip, which is more resistant to ambient noise but less reliable for threshold measurements at low

frequencies, presents a challenge for the design of a self-fitting hearing aid.

Automated Audiometry

Feasibility. Automated audiometry is not a new invention. As early as 1947, Békésy developed an instrument that enabled automatic measurement of an individual's pure-tone thresholds (Békésy, 1947). The audiometer worked by automatically and continuously increasing the intensity of a tone in 2 dB steps when a signal button was pressed and by decreasing the intensity of the tone when the signal button was released. Other automated audiometers followed suit, particularly after the introduction of computers in the early 1970s (e.g., Sakabe, Hirai, & Itami, 1978; Sakabe, Ooki, Terai, Shinozaki, & Itami, 1975; Wood, Wittich, & Mahaffey, 1973). As technology advanced, the instruments became smaller and easier to self-administer, and recent studies have found that modern computer-assisted air-conduction audiometry is as reliable and accurate as manual audiometry for both adults (Ho, Hildreth, & Lindsey, 2009; Margolis, Glasberg, Creeke, & Moore, 2010; Swanepoel, Mngemane, Molemong, Mkwanaazi, & Tutshini, 2010) and children (Margolis, Frisina, & Walton, 2011). Validity and reliability further extend to the use of contralateral masking (e.g., Ho et al., 2009; Margolis et al., 2010; Wood et al., 1973) and bone conduction measurements when using consistent placement (forehead or mastoid) of the bone conductor (e.g., Margolis & Moore, 2011; Swanepoel & Biagio, 2011; Wood et al., 1973).

The procedures used in computer-controlled audiometry have varied, but in most cases, follow established procedures for performing manual audiometry as closely as possible. However, because a computer can handle some complex decision-making processes faster and more consistently than humans, more complex rules could be included in the automated procedure that could increase the validity and reliability of threshold measurements. This could be an advantage in self-fitting hearing aids to counteract other variables, such as self-placement of the instant-fit tip in the ear, which may slightly reduce the reliability of the measurements. In a pilot study conducted at the National Acoustic Laboratories, an automated procedure using a nonstandard algorithm was examined for potential validity and reliability against a standardized manual procedure. The automated procedure used an adaptive paradigm in which the presentation level was initially decreased in 4-dB steps when there was a response and increased by 5 dB when there was no response. After the first nonresponse, the step size of the decrements was reduced to 2 dB. Changes to the adaptive level continued until the standard error (*SE*) of the levels at which reversals occurred was less than 1 dB, or a maximum of 4 reversals had occurred. The algorithm contained nonstimulus periods to check that the participants were responding appropriately. The proportion of nonstimulus periods depended on the participant's previous rate of inappropriate button presses.

Table 1. The Pearson's *r* Correlation Coefficients Measured Between Test Conditions

Condition	250 Hz	1000 Hz	4000 Hz
AutAud (1) vs AutAud (2)	0.98	0.99	0.99
ManAud (1) vs ManAud (2)	0.91	0.95	0.98
AutAud (1) vs ManAud (1)	0.96	0.98	0.99
AutAud (2) vs ManAud (2)	0.91	0.96	0.97

Note: AutAud = automated audiometry, ManAud = manual audiometry. (1) = first measurement, (2) = second measurement.

Threshold data were measured twice manually and automatically at 250, 1000, and 4000 Hz on each ear of 23 participants with varied degrees of hearing loss. The manually measured thresholds were obtained by an audiologist with more than 15 years of clinical experience, using the MedRx AVANTI A²D⁺ computer-controlled audiometer and the Hughson-Westlake technique. The automated procedure was implemented on a PC with sounds presented through a Roland Edirol FA-101 audio interface. In the case of manual audiometry, stimuli consisted of a pure tone, while trains of three pure tones, each 290 ms in duration with intervening gaps of 140 ms (IEC 645-1; International Electrotechnical Commission [IEC] 1987), were presented during automated audiometry. A conventional response button was used during manual audiometry, whereas a colored key on a numerical keypad was used during automated testing. Both set of thresholds were obtained through calibrated (ISO 389.2, 1994) ER-3A insert earphones that were not removed from the ears between measurements.

Measurements on the 46 ears were treated as independent observations and compared across time and method. Table 1 lists the Pearson's *r* product moment correlation coefficients for each frequency for each set of test-retest measurements (first manual vs. second manual, and first automatic vs. second automatic) and for each set of comparison measurements (first manual vs. first automatic, and second manual vs. second automatic). All comparisons produced highly significant correlations ($r \geq 0.91$; $p < .001$), meaning that the measurements were very repeatable across both time and method.

Table 2 lists the mean threshold differences measured between test conditions at each frequency. Across frequencies, the mean threshold differences are -0.10 dB and 0.04 dB for the automated and manual procedure, respectively, and 1.39 dB and 1.47 dB for the first and second set of comparisons, respectively. The mean difference values obtained between manual and automated audiometry are similar to those reported by Jerlvall, Dryselius, and Arlinger (1983), Ho et al. (2009), and Margolis et al. (2010). Across the two sets of measurements, thresholds were no more than 5 dB apart in 83.5%, 80%, and 83.5% of ears, and no more than 10 dB apart in 96%, 95.5%, and 95.5% of ears at 250, 1000, and 4000 Hz, respectively. Overall, the nonstandardized procedure

Table 2. The Threshold Differences in dB Between Test Conditions

Condition	250 Hz	1000 Hz	4000 Hz
AutAud (1) vs AutAud (2)	-0.39 (2.7)	0.02 (2.5)	0.24 (2.2)
ManAud (1) vs ManAud (2)	0.00 (6.9)	-0.65 (5.1)	0.76 (4.7)
AutAud (1) vs ManAud (1)	-0.43 (4.8)	2.87 (3.7)	1.74 (4.2)
AutAud (2) vs ManAud (2)	-0.04 (6.6)	2.20 (4.8)	2.26 (5.4)

Note: Numbers in parentheses show the standard deviation values in dB. AutAud = automated audiometry, ManAud = manual audiometry. (1) = first measurement, (2) = second measurement.

seems to be a valid approach to measure threshold levels automatically.

From Table 2 it can be seen that the standard deviation values of the test-retest differences are lower for the automated than for the manual procedure at each frequency (by 3 dB, on average), suggesting that repeatability was better with the automated procedure. Relatively lower intraparticipant standard deviation values with the automated than the manual procedure were also observed in Jerlvall et al. (1983) and Ho et al. (2009) although the standard deviation values obtained in this study for the automated procedure are markedly lower. The difference in step size used in the present study (2 dB with the automated and 5 dB with the manual procedure) may partly explain this discrepancy as data in the other two studies were obtained using a 5 dB step size in both manual and computerized audiometry. This observation would indicate that it would be better in terms of consistency to use a final step size less than 5 dB for threshold measurements.

In summary, many studies have demonstrated that automated procedures that closely follow recommended procedures for measuring air conduction thresholds produce valid and reliable audiometric results. A pilot study conducted at our laboratory further demonstrated that a nonstandardized implementation of an automated method to obtain threshold data, which could easily be implemented in a self-fitting hearing aid, was as valid as a standardized manual method, and more reliable. The higher level of consistency measured with the nonstandardized automatic method was presumably in part due to the smaller final step size used.

Challenges. Past publications on automated audiometry have almost all pointed out that automated audiometry, although valid and reliable, cannot be used with all clients and should preferably be supervised by a qualified clinician. One of the potential risks of the self-fitting hearing aid is that a person is fitted with inappropriate amplification due to invalid threshold measurements. Several steps can be taken to minimize this problem. First, it is critical that instructions are clear and easy to understand across multiple languages, cultures, and levels of literacy. The important role of health literacy when devising a set of instructions and the impact of demographic factors on the ability to follow instructions are discussed in several of the articles in this issue (e.g., Caposecco,

Hickson, & Meyer, 2011). Second, it would be possible to incorporate some rules in the automated audiometer for invalidating the threshold measurements if the response pattern is unusual or erratic and hence deactivate the instrument to prevent the provision of inappropriate amplification. This has been successfully demonstrated by Margolis et al. (2011). In their implementation, a quality assessment method (QUALIND^R; Margolis, Saly, Le, & Laurence, 2007) is incorporated that predicts the accuracy of the test results. The method uses a range of quality measures, such as time per trial, average 1 kHz test-retest difference, false alarm rate, and quality check fail rate, that are included in a multiple regression analysis to predict the average absolute difference between predicted and measured thresholds. If threshold measurements obtained through the self-fitting hearing aid were deemed invalid, the instructions could ask the person to see a health professional to have the instruments activated again and to obtain help with the audiometric measurements.

It would also seem that in all past studies on automated audiometry, placement of the transducer, including the insertion of ear tips when insert earphones were used, was managed by a qualified person. Thus, it is currently uncertain how valid and reliable automatically measured thresholds are when, in the case of the self-fitting hearing aid, the instant-fit tips are placed in the ear by the hearing aid user, or another layperson. This is an important question to address in future studies.

Medical Contradictions

Feasibility and challenges. As pointed out earlier, the audiogram helps identify hearing losses associated with medically or surgically treatable conditions. The characteristics to look for include asymmetry and hearing loss with a conductive component. In a clinical setting, the hearing aid candidate would be referred for further medical tests if these characteristics are picked up by the clinician. Including features that could enable detection of significant asymmetry or conductive loss would certainly increase the level of sophistication of the self-fitting device and make it a more complete solution, but would also likely increase the complication of the instructions the users have to follow to self-administer the audiometric measurements. If asymmetry or a conductive hearing loss was suspected, amplification could be deactivated, and the user advised to seek professional help.

A potential limitation of applying automated audiometry in a self-fitting hearing aid is that it may be viable only for simple sensorineural hearing loss. The feasibility of detecting the presence of an asymmetrical, conductive, or mixed hearing loss when measuring thresholds in situ through hearing aids has not yet been explored. Detection of an asymmetrical hearing loss and the provision of masking could potentially be achieved through a pair of binaurally linked instruments that enable a comparison of the threshold measurements of the two ears. In this context, it is worth noting

Figure 2. The threshold levels at which a tone was just audible in noise shown as a function of hearing threshold levels

Note: Data were averaged across 1000 and 2000 Hz. Participants with a sensorineural loss are shown with open circles, and participants with conductive loss are shown with filled diamonds.

that interaural attenuation will vary with the openness of the instant-fit tip used for threshold measurements. If a fairly occluded tip is used for threshold measurements, the interaural attenuation will likely approach the 60 to 70 dB assumed with insert earphones, and consequently the ability to perform masking would be less important.

Enabling bone conduction thresholds to be directly measured poses a bigger challenge. By chance, data have emerged from our laboratory suggesting that it may be possible to identify conductive components from air conduction thresholds measured in quiet and in noise. Figure 2 shows the signal-to-noise ratio (SNR) at which pure tones at 1000 and 2000 Hz, on average, were just audible in an amplitude-modulated narrow-band noise, as a function of the average air-conduction threshold measured across 1000 and 2000 Hz. The filled diamonds show data from participants who had an average air-bone gap greater than or equal to 15 dB across the two frequencies. It is of interest that three participants, all of whom had a conductive component to their hearing loss, performed close to normal, and that another two participants with conductive loss performed better than average for their degree of hearing loss. That is, it seems like people with conductive hearing loss may be better able to take advantage of gaps in the noise than people with pure sensorineural hearing loss. From this data, it would also appear that not everyone with a conductive component may be identified this way although this may depend on factors not controlled for in this data set. Some problems with the instrumentation were found after this data had been collected, which are most likely to have affected data collected at lower and at higher frequencies.

A study is currently underway to fully investigate whether an air-bone gap may be detected from air conduction

thresholds measured in quiet and in noise. If a tone-in-noise test can be used to isolate the sensorineural component of a hearing loss, and can be performed reliably in situ, then an air–bone gap may be identified from a conventional pure tone test presented in quiet and in noise. Such tests could be implemented and managed in a self-fitting hearing aid.

Conclusion

Current data suggest that it is likely feasible to obtain valid and reliable threshold data in a self-fitting hearing aid through automated in situ audiometry although this still has to be directly verified. Issues that require further investigations and that need to be overcome to ensure both successful threshold measurements by a self-fitting hearing aid and usage of the device include (a) the design of clear instructions for correctly inserting the hearing aid into the ear, and starting and managing the automated procedure; (b) the selection of the best transducer and coupling combination that will enable the widest range of thresholds to be tested; (c) a method that allows the hearing aid microphone to monitor ambient noise and to interrupt the self-fitting process if threshold measurements are contaminated by ambient noise; and (d) the application of both masking and bone conduction testing to identify potential medical contraindication(s) to hearing aid fitting.

Author's Note

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