academia

The verification of fitting hearing aids with in situ measurements

WHITE PAPER

author:
Elisa Veronese, Ph.D.

The implementation and utilization of in situ Real-Ear Measurements (REM) gives the hearing care professional an objective, reproduceable, and quantitative tool to use with the fitting of the hearing instruments or amplifying devices. A circumstance in which the advantages offered by an REM system are particularly evident is the programming of a hearing aid for a child. If the hearing health care professional only references the measurements provided by the manufacturer (typically acquired with a coupler without taking account of the measurements in situ), there would be the risk of an excessive amplification of sounds at the eardrum.

This is based on the notion that the ear canal volume of a pediatric patient is smaller than an adult ear canal volume. If one presents the same intensity of a signal, the sound pressure generated in a small cavity is greater than the one generated in a cavity of larger volume.

An REM (Real-Ear Measurement) system allows the practitioner to accurately measure the performance of an amplifying device directly in the patient's ear canal. The acquired measurement shows the real sound pressure level (intensity) produced by the hearing aid at the patient's eardrum and allows the practitioner to adjust the gain of the hearing aid to meet the patient's needs. The time required to carry out an in situ measurement is fully rewarded in terms of quality of fitting, enhances the acceptance of the hearing aid by the patient and reduces follow-up time. Another advantage of an REM system involves the area of counselling. During the measurement session it gives the patient and third party a visual representation of how the amplifying device is affecting the patient's audibility.

INTRODUCTION

The acquisition of in situ measurements (Real-Ear Measurement, REM) is a reliable and repeatable method for quantifying the intensity of a stimulus in the patient's ear canal. A measurement performed directly in the ear allows one to verify the gain of the amplifying system. The amplifying system may consist of the hearing aid, ear mold and tubing, ear hook and any sound filtering due to the external ear.

To perform an REM examination, a series of stimuli (with a well-known spectrum and intensity), are presented to the hearing-impaired individual through a loudspeaker. The generated sound pressure is measured by means of two dedicated microphones, one close to the eardrum and the other close to the pinna. The signals acquired allows not only to evaluate the performances of the hearing aid directly in the ear canal of the patient, but but also to adjust the gain the gain of the amplifying device to the desired levels.

The purpose of this article is to provide an essential guide to understand the aims and benefits associated with an REM examination. Additionally, simple instructions to perform this examination with the REM system Trumpet, developed by Inventis srl, will be presented in detail.

AIM OF AN REM SYSTEM

The purpose of an REM system is to verify, , by measuring them in situ, the amplification levels produced by a hearing aid, after its gains have been adjusted. Measurements may then be compared to "target curves". The target curves are calculated both on the basis of the audiogram and other characteristics of the patient, and considering the specifics of the hearing aid used. The main purpose of target curves is to provide an indication of the gains to be set on the hearing aid to optimize the auditory capabilities of the subject being examined. IIn literature there are several algorithms that provide an estimate of such curves in. Each of these algorithms necessarily requires the insertion of the patient's pure tonal audiometry.

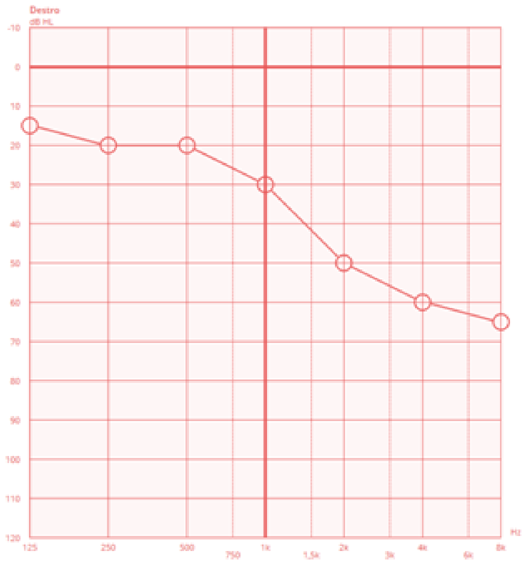

Fig. 1. Audiogram acquired in air conduction for a patient's right ear

Figure 1 shows an example of an audiogram acquired in air conduction for a patient's right ear. In this article, the audiogram in figure 1 will be used to proceed with the explanation of the whole REM examination.

The advantages offered by an REM system during a fitting procedure are many:

the measurements are acquired in situ, therefore they are much more reliable than any measure carried out using a coupler. The amplification effects due to the conformation of the ear canal may have a considerable inter-individual variability, which can only be adequately considered by means of an in situ measurement;

- the measurements taken can be used as baseline if, at a later time, the patient decides to change the type of hearing aid;
- both the clinician and the patient ccan visually appreciate the effects of an accurate tuning;
- it is possible to check the functionality and the benefits provided by potential advanced features of a hearing aid such as the implementation of noise reduction, directionality and so forth;
- the patient and his relatives have the opportunity to assess how the use of the hearing aid would improve the patient's quality of life by comparing his residual auditory abilities with those achieved using the device;
- if the hearing aid is repaired and the replacement component has a different frequency response, the hearing aid can be adjusted to match the amplification envelope of the previous REM result;
- recent studies show that the more the measurements align with the target curves, the more the patient benefits from the use of the hearing aid (Baumfield & Dillon, 2001; Mueller et al., 2005).

THE REM SYSTEM

To perform in situ measurements, it is necessary to use an REM system, such as the Inventis Trumpet (Figure 2). The main components of an REM system are a loudspeaker and four microphones suitably calibrated which are mounted within two probes. In particular:

- the speaker must be equalized so that the sounds sent to the patient are emitted at the intensity set by the hearing care professional. Every time the environmental setup of enviromental setup of measurement is modified is modified, a speaker equalization must be performed by the hearing care professional;

Fig. 2 — The bow with probe and reference microphones are connected to the main body of the instrument, which acts as loudspeaker and contains the control electronics, it is connected the bow with probe and reference microphones.

- the two probe microphones, one for each ear, allow one to measure the signals arriving at the eardrum of the patient through a silicone tube inserted in the ear canal;
- the two reference microphones, one for each ear, record the signals arriving at the base of the pinna of the patient being examined.

A computer typically controls the REM system. Hearing aid manufacturers fitting software may also be installed on the same computer to enable gains adjustment to occur concurrently. The Trumpet interfaces with the computer through the USB port.

The steps required to conduct an REM exam utilizing the Trumpet REM are described in detail below. Inventis Maestro software is used to control the Trumpet. Maestro can work either as stand-alone software or as a NOAH module.

PRELIMINARY PROCEDURES

An REM examination does not require a silent cabin: it is sufficient to carry out measurements in a quiet room, in which any background noise is at least 10 dB lower than the test signals. Before proceeding with the acquisition of the REM data, it is relevant to consider ambient noise level as well as other factors that may affect the measurements (Hawkins & Mueller, 1986, 1992; Ickes et al., 1991). The preliminary operations that must always be performed before carrying out an REM examination are summarized below.

OTOSCOPY EXAM

The presence of earwax or exudate in the ear canal could obstruct the insertion of the probe tubes, or possibly even occlude the probe tubes. Therefore, a preliminary otoscopic exam is necessary to identify such situations. The otoscopic examination can also provide detailed information on the anatomy of the ear canal of the patient being examined. This information will be useful for the operator during the insertion of the probe tubes.

PROBE TUBE CALIBRATION

The probe tubes calibration takes into account the acoustic effects introduced by the tubes used during the examination. Calibration is necessary to make the microphone and probe tubes “acoustically invisible”. Figure 3 shows how to position the probe tube in order to proceed with the calibration. The probe tube tip must be inserted as close as possible to the reference microphone, using the appropriate guides. Calibration is performed by placing the bow in front of the loudspeaker, about a meter away.

Fig. 3 — Probe tube calibration: recommended placement

The probe tubes must be calibrated every time they are changed; accordingly, every time the test is conducted on a new patient, the system will prompt the user to run the calibration of the tubes before the first measurement is made.

PLACEMENT OF THE SPEAKER

Several studies have shown that the placement of the loudspeaker relative to the patient, in terms of both distance and azimuth, interferes with the measurements acquired, and then with the results of an

REM examination (Hawkins & Mueller, 1986, 1992; Ickes et al. 1991).

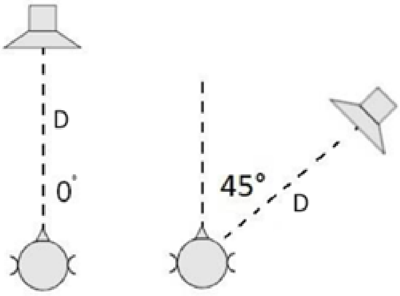

Fig. 4 — It is recommended to place the patient at a distance between 0.5 and 1 meter from the speaker and at an angle of 0°. Only for monoaural measurement, it is possible even to place the speaker at an angle of 45°.

PLACEMENT OF PROBE TUBES

Typically, the silicon tube is positioned so that the distance between its tip and the eardrum is no more than 3-5 mm (Dirks & Kincaid, 1987). The presence of a ruler in the bow and the probe tube black ring can be helpful. An example of a correct insertion of the probe tube in the ear canal is shown in Figure 5.

Fig. 5 — Example of correct insertion of a probe tube inside the ear canal

SELECTION OF THE FITTING RULE

Prescriptive methods (or fitting rules) are algorithms aimed at determining a target amplification curve (target curve) that, according to the author of the method, represents the ideal listening level for the user of the hearing aid.

Several prescriptive methods have been formulated since the first half of the last century. Currently, the most commonly used procedures are the result of the gradual refinement of the first proposed rules, coupled with several population studies. In particular, the NAL (National Acoustic Laboratories) research group suggests the use of two non-linear methods (NAL-NL1 and NAL-NL2) whose rationale is to equalize the intensity of a signal on all of its frequencies. The University of Western Ontario research group has developed a non-linear method as well (DSL 5.0, Desired Sensation Level), whose purpose is to optimize the speech audibility, minimizing the annoyance associated with too intense sounds.

MEASUREMENTS ACQUISITION

An REM system allows the operator to acquire many types of measurements, defined in ANSI and IEC standards (American National Standards Institute (ANSI) S3.46, 2013, IEC 61669, 2015) and classified in response or gain measurements. Response measurements (REAR, REOR, REUR) are acquired by the probe microphone near the eardrum, in response to an acoustic signal emitted by the loudspeaker. The gain measurements (REAG, REIG, REOG, REUG) are differential measurements, calculated by subtracting the signal measured by the reference microphone from the signal acquired with the probe microphone.

The choice to use response or gain measurements provides a different way to quantify the signal amplification in the ear canal of the patient. The following paragraphs describe the methods of acquisition of the different measurements used in the whole procedure.

UNAIDED MEASUREMENTS

Once the probe tube has been inserted into the ear canal properly, it is possible to proceed with the REM examination by acquiring the unaided measurements. This measurement is accomplished without any hearing aid to assess the natural amplification of the patient's ear canal resonance. The acquisition of an REUG (Real-Ear Unaided Gain) curve, although recommended, is not strictly necessary, since each fitting rule implements its own predicted average REUG that can be used for following assessments. The use of a predicted average REUG can, however, lead to inaccurate results, especially if the patient's ear canal is not of average length, diameter, or size.

To acquire the REUG curve, the user can choose whether to use a white noise or a pink noise that will be sent by the speaker at a predetermined intensity (usually 70 dB SPL). The choice to display together with the measurement the predicted average REUG can be a useful reference to verify in real time if the signal being acquired is reliable; otherwise, the probe tube may have not been properly inserted. In this situation, it is possible to change the placement of the probe tube until the two curves are compatible. Figure 6 shows the acquisition of a typical REUG curve.

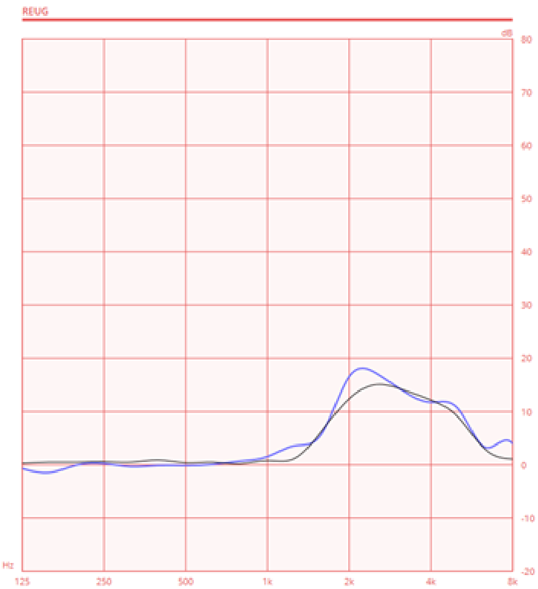

Fig. 6 — After inserting the probe tube into the patient's ear canal and deciding which fitting rule to apply (DSL v5.0, NAL-NL1 or NAL-NL2), it is possible to acquire the REUG curve of the ear under examination. Select the type of curve (unaided) and choose the type and intensity of the signal to use (in the example, 70 dB SPL Pink noise). As soon as the loudspeaker starts sending the signal, the REUG curve acquired in real time (purple curve) will appear on the graph. The choice to display the predicted average REUG (black curve in the graph) simultaneously can be a useful reference.

OCCLUDED MEASUREMENTS

The hearing care professional can now proceed inserting the hearing aid into the patient's ear canal, paying attention to minimizing possible displacements of the probe tube. In 'OCCLUDED' mode, occlusion response (REOR) or occlusion gain (REOG) measurements can be taken with the hearing aid inserted and switched off, in order to establish the level of occlusion introduced by the physical presence of the hearing aid. An example of acquisition of an REOG curve is shown in Figure 7. After selecting the type and intensity of the signal to be employed, it is possible to display and then acquire the curve. Thereby, assessing the occlusion effect as well as the attenuation of the signal due to the physical presence of the hearing aid in the ear canal. Typically, in the case of an occlusive hearing aid, it is expected a gain reduction compared to the REUG curve in the frequency range corresponding to the natural resonance region of the ear canal (i.e. 1000 to 2500 Hz). Conversely, if the patient is wearing a non-occlusive hearing aid, as in Figure 7, the gain loss respect to the REUG curve will be considerably lower.

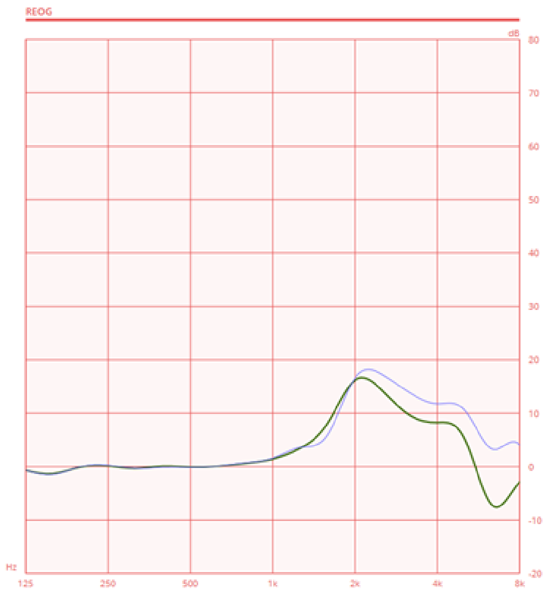

Fig. 7 — To acquire the REOG curve of the ear under examination, select the type of curve (Occluded) and choose the type and intensity of the signal used for the acquisition of the REUG curve (in the example, a 70 dB SPL Pink noise). As soon as the loudspeaker starts sending the signal, the REOG curve acquired in real time (green curve) will appear on the graph. A comparison with the REUG (purple curve in the graph) previously acquired allows to quantify the gain loss due to the occlusion effect of the hearing aid.

AIDED MEASUREMENTS

In 'AIDED' mode, aided response (REAR) or aided gain (REAG) measurements are acquired with the hearing aid inserted and switched on: the signals acquired show the intensity of the sound pressure at the eardrum after being amplified by the ear canal and the hearing aid. Even here, the hearing care professional selects the type and intensity of the signals the speaker will generate. Typically, speech-shaped signals such as ICRA, (International Collegium of Rehabilitative Audiology, refer to icra-audiology.org for more details), or ISTS (International Speech Test Signal, (Holube & al., 2010)) are used. The frequency spectrum of these signals simulates real speech. Moreover, in order to reproduce different credible situations, different measurements at different intensities should be administered.

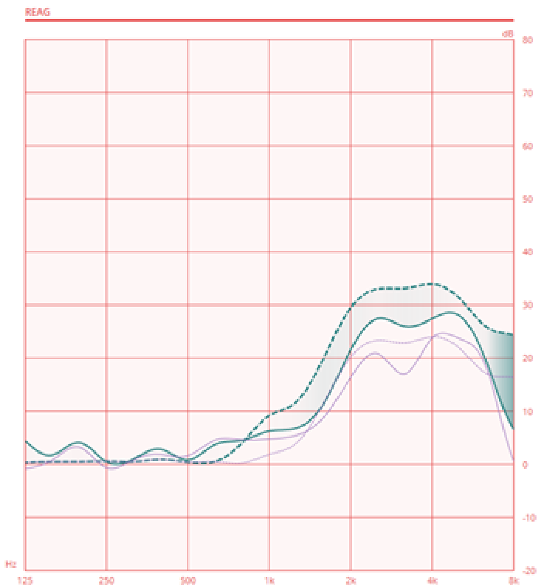

Fig. 8 — Up to five REAG curves can be acquired by selecting the type of curve (Aided) and setting, for each of the available measurements, the type and intensity of the signal to use: in the example shown, the green curve and the purple one corresponds to an ISTS signal, respectively sent at 65 and 80 dB SPL. The continuous curves correspond to the REAG acquired; the dashed ones are the corresponding target curves calculated by the fitting rule selected. The software allows, if desired, to highlight the area where the measured curve deviates more from its target.

Figure 8 shows the result of the acquisition of two aided curves. The graph represents the two REAG (continuous curves), which are associated with the corresponding target curves calculated by the fitting rule (dashed curves) selected: the purpose of this type of measurement is to assess that the acquired curves deviate as little as possible from the previously selected target curves.

The aided curves described so far represent the gain contribution provided by the hearing aid and the ear canal. To qualtify the contribution provided by the hearing aid only, select the option INSERTION: an REIG (Real-Ear Insertion Gain) measurement will be acquired.

When an aided or an MPO measurement (see the paragraph MPO measurements for more details) is being performed, it is possible to take advantage of the software option called on top (Figure 10): this option allows the operator to work simultaneously with the software of the hearing aid, displaying in real time as a gain adjustment can be reflected in the curve acquired at the REM system's microphones. Using the on top mode, the Maestro window is displayed in a smaller format and always in foreground. Figure 9 shows an example of how to use the on top option: the operator who is performing an REM examination can adjust the gains of the hearing aid and assess at once if the measurement acquired (in the example, an 80 dB SPL REAG) moves close or away from the corresponding target curve.

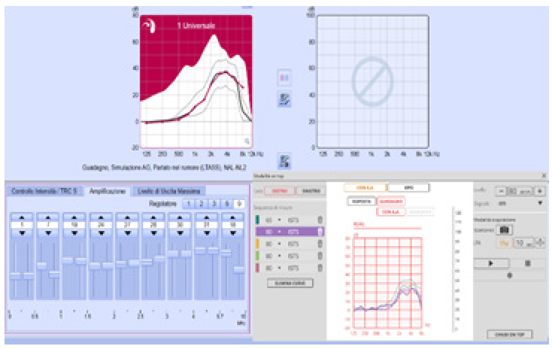

Fig. 9 — Use the On Top mode during an AIDED measurement: along with the software of the hearing aid, the REM window is displayed in a reduced format so that it is possible to check in real time how the adjustment of the hearing aid gains is reflected in the REAG curve acquired.

MPO MEASUREMENTS

A properly functioning hearing aid should not only be able to amplify satisfactorily the external signals, but it must be set so that the amplification provided is not dangerous or annoying for the patient. In 'MPO' (Maximum Power Output) mode, the instrument can provide response measurements to check that the output from the hearing aid does not exceed the Uncomfortable Level (UCL) identified for the patient, even when a signal of high intensity (typically 85 dB SPL) is generated. See Figure 10.

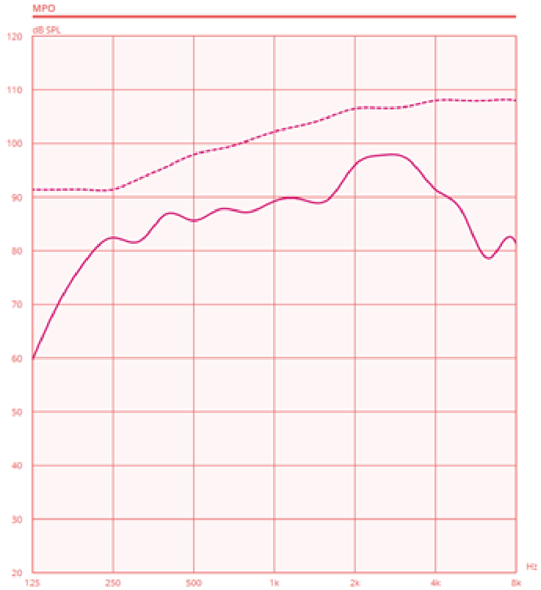

Fig. 10 — Selecting the MPO mode, the speaker sends a sound at 85 dB SPL. In the graph, the measurement acquired by the probe microphone (continuous curve) should not exceed the should not exceed the dashed curve suggeste should not exceed the dashed curve suggeste, suggested by the fitting rule or customized.

LIVE MEASUREMENTS AND COUNSELLING

It may be particularly useful for the patient and his/her family members to be able to see if and how much the use of a hearing aid can improve the patient's hearing ability. The LIVE mode within Maestro allows one to obtain this measurement. This test mode has counselling purposes: it allows performing a comparison between the response measured with the hearing aid inserted and active, with the estimated response without the hearing aid. An example of how to use this test modality is shown in Figure 11: the combined visualization of the two curves (level of sounds heard with and without hearing aid) and the subject's audiogram allows one to appreciate immediately and intuitively the benefits the adoption of a hearing aid can provide. It is relevant to underline the influence that this test modality can have: in fact, the operator can only assess whether the patient is a good candidate for the application of a hearing aid, but the final decision regarding the adoption of the device depends on the patient. The use of a device which allows the subject to appreciate in real time the improvement of his auditory ability can therefore be a great help for the decision maker. In addition to the speech-like signals available, such as ISTS or ICRA, it is possible to use the voice of either the operator or the patient's relatives as s stimulus. This creates an even more comfortable and familiar situation in order to let both the patient and the relatives appreciate the advantages a hearing aid could provide.

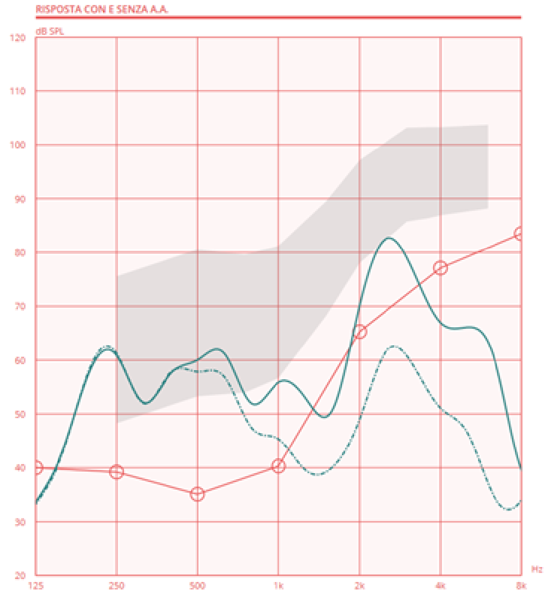

Fig. 11 — Use of the live mode and comparison between the signal that the patient hears without the hearing aid (dashed curve) and the signal he would hear with the hearing aid (continuous curve). The gray region represents the speech banana modified according to the audiogram of the subject being examined. Since the perceivable sounds are those that exceed the red curve, which corresponds to the patient's pure tone audiometry, the advantages a hearing aid could provide are immediately noticeable.

CONCLUSIONS

The acquisition of in situ measurements represents the most efficient method to ensure the patient could achieve the best hearing aid fitting. In fact, we can think of having adjusted properly the gains of a hearing aid only when the quality of the sounds reproduced by the hearing aid itself is optimized according to the patient's needs and preferences. Such a balance between audibility and optimization of the stimuli quality can only be obtained by measuring the sounds produced by the hearing aid directly in the ear of the patient who wears the device.

The execution of an REM examination necessarily involves an initial investment of time for the operator. However, this investment results in a subsequent significant reduction of appointments for adjusting the gains of the hearing aid. For this reason, in situ measurements, which in Anglo-Saxon countries have been recommended in the hearing health care provider guidelines for more than fifteen years, are achieving more and more popularity (Mueller & Picou, 2010).

GLOSSARY

MPO: Maximum Power Output. Measurement of response in the ear with hearing aid inserted and switched on, and input consisting in a pure tone sweep at 85 dB SPL.

REAG: Real-Ear Aided Gain. Measurement of gain in the ear with hearing aid inserted and switched on. It considers the amplification provided by the hearing aid and the ear canal.

REAR: Real-Ear Aided Response. Measurement of response in the ear with hearing aid inserted and switched on.

REIG: Real-Ear Insertion Gain. dB SPL difference between REAG and REUG measurements or, similarly, dB SPL difference between REAR and REUR measurements. It considers only the amplification provided by the hearing aid, without any contributions of the ear canal.

REOG: Real-Ear Occluded Gain. Measurement of gain in the ear with hearing aid inserted but switched off.

REOR: Real-Ear Occluded Response. Measurement of response in the ear with hearing aid inserted but switched off.

REUG: Real-Ear Unaided Gain. Measurement of gain in the ear without hearing aid. It considers the natural amplification provided by the ear canal.

REUR: Real-Ear Unaided Response. Measurement of response in the ear without hearing aid.

BIBLIOGRAPHY

American National Standards Institute (ANSI) S3.46. (2013). American National Standard Methods of Measurement of Real-Ear Performance characteristics of Hearing Aids.

Baumfield, A., & Dillon, H. (2001). Factors affecting the use of perceived benefit of ITE and BTE hearing aids. Br Jour Audiol (35), 247-258.

Dirks, D., & Kincaid, G. (1987). Basic acoustic considerations of ear canal probe measurements. Ear and Hearing (8), 60S-67S.

Hawkins, D., & Mueller, H. (1986). Some variables affecting the accuracy of probe tube microphone measurements. Hearing Instruments (37), 8-12.

Hawkins, S., & Mueller, H. (1992). Procedural considerations in probe-microphone measurements. Probe Microphone Measurements: Hearing Aid Selection and Assessment, 67-90.

Holube, I., & al. (2010). Development and analysis of an international speech test signal (ISTS). Int Jour Audiol (49), 891-903.

Ickes, M., & al. (1991). Effects of reference microphone location and loudspeaker azimuth on probe tube microphone measurements. J Am Acad Audiol, 156-163.

IEC 61669. (2015). Measurement of real-ear acoustical performance characteristics of hearing aids.

Mueller, H., & al. (2005). Fitting hearing aids to adults using prescriptive methods: an evidence-based review of effectiveness. J Am Acad Audiol(16), 448-460.

Mueller, H., & Picou, E.M. (2010). Survey examines popularity of real-ear probe-microphone measures. Hear J 63(5), 27-32.

Product Insight - Rev02 • Date: 2024.03.26

Audiology & Balance

INVENTIS S.r.l.
CORSO STATI UNITI, 1/3
35127 PADOVA – ITALIA
TEL: +39.049.8962 844
FAX: +39.049.8966 343
info@inventis.it
www.inventis.it