Chapter 4: Introduction and Getting Ready for Real-Ear Probe Microphone Measures

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ABSTRACT

Probe microphone measurements are an essential step in an individualized hearing aid fitting. These measurements allow audiologists to account for the individual's hearing and ear canal acoustics when programming hearing aids. An evidence-based hearing aid fitting includes matching the measured output of the hearing aids to targets for each input level and frequency. This allows the audiologist to confidently counsel the patient that the acoustic fitting is accurate, and the next step is for the individual to use the amplification during all waking hours to adapt to the newly amplified sounds. This also avoids mistakes such as overamplification or insufficient gain, which can endanger the patient and/or lead to a compromised fitting.

KEYWORDS: real-ear probe microphone measures, coupler microphone leveling, coupler, hearing aid test box, first fit, audibility, calibration

This chapter will introduce you to the parts of the probe microphone system and lead you through the set-up for measurements. Chapters 5 and 6 will provide you with guidance on how to use this powerful measurement tool to customize hearing aid fittings for your patients and ensure you are following evidence-based practices in hearing aid fitting.

Real-ear probe microphone measurements are used to measure the sound pressure level (SPL) in the ear canal. The level produced by a hearing aid is different in an ear canal than it is

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in a coupler in a test box. This difference occurs because the properties of the ear canal (length, structure, etc.) impact the sound in a way that the coupler (representing an average ear) in the test box does not. Each person's ear canal is a different shape and size; so, the acoustic impact of the individual's ear must be accounted for in an evidence-based, individualized hearing aid fitting. The ability to perform, interpret, and act upon this information is part of what the audiologist "brings to the table" in a hearing aid fitting; it is a critical component of an individualized process for the patient.

The probe microphone system can be used to obtain a variety of measures. Below is a list of terms and definitions[1] that are important to know when working with the real-ear probe microphone system. If you are talking about measurements you make, you do not want to say that you "do probe microphone measures" that could be one of many measures. You want to be specific and indicate the measure to which you are referring so the person speaking with you will know what your goal is in performing that measure. These measures are all completed with the probe microphone appropriately situated in the individual's ear canal and measurements are made across frequency. Keep in mind, input is the level of the sound that is produced outside of the ear canal (through the system's loudspeaker), output is the resulting SPL in the ear canal (often after being processed through the hearing aid), and gain is output minus input. Therefore, gain is not a measure, but a mathematical formula.

- **Real-ear unaided response:** The sound pressure measured in an open ear (no hearing aid) when a known sound is produced by a loudspeaker.
- **Real-ear unaided gain (REUG):** Difference in decibels between the measured SPL in an open ear and the original input SPL.
- **Real-ear occluded response:** The sound pressure measured in an ear with a hearing aid in place but turned off. This can also be the sound pressure measured in an ear with an earplug in place.
- **Real-ear occluded gain:** The difference between the input signal and the output measured in an ear with a hearing aid in place but turned off (or of an earplug).
- **Real-ear aided response (REAR):** Output from a hearing aid placed in an ear canal measured in decibels (dB) SPL. In the Verifit system, this is often referred to as "Speechmapping."
- **Real-ear aided gain (REAG):** Difference obtained when subtracting the REAR from the input signal.
- **Real-ear insertion gain:** Difference in dB between the REAG and the REUG.
- **Real-ear to coupler difference (RECD):** Difference in dB of the output of a sound presented to a 2-cc coupler and the output of an identical sound presented to an individual's ear.
- **Real-ear to dial difference:** Difference in decibels from a specified audiometer dial setting (e.g., dB hearing level [HL] at a particular frequency) and the dB SPL measure of the same sound in the individual's ear canal.
- **Real-ear saturation response:** The output (dB SPL) of a hearing aid at its maximum output level (input signal sufficient to saturate the hearing aid response).

The goal of a hearing aid fitting is to make the range of sounds one encounters throughout a day audible, while ensuring comfort and good sound quality. We address a patient's communication goals with hearing aids (e.g., understanding or comfort in noise) through special features that may include a remote microphone, directional microphones, noise suppression programs, coupling to assistive devices, etc. In addition, we must ensure safety in the patient's auditory environment by providing appropriate coupling to both landline and mobile telephone devices, as well as making sure they can respond to alerting signals. The individual's ability to hear doorbells, telephone ringers, and smoke detectors, among other warning signals must be addressed. Some of these goals may be accomplished through supplementing the acoustic signal (e.g., captioning, speech-to-text, vibrotactile signals). Table 1 lists this common set of goals. Our goal of returning audibility to the entire input range of sounds (soft, moderate, and loud input levels) is tempered by the degree

Table 1 Hearing aid fitting goals

1. Audibility
2. Comfort
3. Good sound quality
4. Addressing patient communication goals
5. Safety in the environment

of hearing loss which may prevent audibility for certain sounds.

Of course, the challenge is to do all of this without having the hearing aids produce feedback, while maintaining physical comfort for the patient wearing the hearing aids, and while providing a style of hearing aids that the patient finds acceptable.

The first goal, audibility, is the underpinning for all the other goals. As David Pascoe[2] once eloquently stated, "Although it is true that mere detection of a sound does not ensure its recognition … it's even more true that without detection, the probabilities of correct identification are greatly diminished."

Therefore, our primary goal for the individual with hearing loss who is pursuing amplification must be audibility for the widest possible input range and across the widest possible frequency range without discomfort (goals 1 and 2). Today's hearing aids generally provide good sound quality (goal 3); and goals 4 and 5 are inextricably linked to the goal of audibility.

The primary goal of amplification (audibility) requires verification. The verification technique should be focused on measuring whether audibility has been achieved while providing an efficient method for repeat measurements to show and verify changes as the hearing aid parameters are manipulated. The goal is to measure audibility at the eardrum of the individual, whether in the real ear or simulated accurately in a coupler.

FIRST FIT AND/OR BEST FIT

The first step in a hearing aid fitting is to enter threshold data into the manufacturer fitting program and select "first fit" or "best fit" from the computer software. Unfortunately, this is often misunderstood as the "final step" when it is most definitely the "first step." The software program does not know anything about the acoustics of the individual ear or the contributing acoustics of the specific hearing aid. The fitting software uses data from an average hearing aid and an average person to provide a starting point. It is important to have a starting point, but there is more work to be done.

Failure to measure audibility in the ear canal implies that the hearing health care professional believes the manufacturer's hearing aid settings provide audibility across various input levels and across a broad frequency range for the individual patient and, therefore, there is no need for verification. Not only is this inaccurate, but if this is the case, there is no need for the audiologist. The individual could input their audiogram into an app and a fitting could be sent to their over-the-counter (OTC) device. Indeed, as of October 2022, this is available to individuals pursing OTC hearing aids or just using their Bluetooth headphones. Therefore, if an audiologist depends on "first fit" without verification and fine-tuning of the hearing aid using evidence-based targets derived from the individual's hearing threshold (dB HL) converted to dB SPL through the application of RECD, they are providing a non-custom fitting. A customized (individualized fitting) relies on real-ear probe microphone measures (or simulated real-ear measures).

ASSESSING AUDIBILITY

To map audibility across the patient's dynamic hearing range, the clinician needs an accurate graph of threshold and uncomfortable loudness level (UCL) displayed in SPL. This represents the individual's dynamic range.

HL in dB is a conversion of SPL to a convenient graphing technique that equalizes minimal audible pressure to 0 dB HL across all test frequencies. The output of a hearing aid is measured in dB SPL and therefore must be compared to hearing thresholds and UCLs displayed in dB SPL.

The first step in having an accurate measurement of audibility is to establish an accurate dynamic range against which to assess the audibility that has been achieved. Assuming hearing thresholds and UCLs are displayed on the audiogram in dB HL, these data need to be converted into SPL accurately. This can be achieved by measuring the real-ear-to-coupler difference (RECD) for the individual (see Chapter 3 for a detailed discussion). This measurement provides corrections for each frequency to accurately convert the HL data to SPL. The evidence-based targets (e.g., DSLv.5,[3] NAL-NL2[4]) are created so that you know where the output for each input level across frequency should be produced mathematically from the dB SPL thresholds. Therefore, if the transformation to dB SPL threshold is not related to the individual, the targets also are not specific to the individual. RECD is one of the most powerful sets of data used in the accurate fitting of hearing aids. With these correction factors, all other verification of the hearing aid can be conducted with the coupler in the test box if desired. The RECD can be applied to these measurements to simulate the sound levels that will be achieved in the ear canal of the individual.

The patient should be made aware of the importance of this measurement. Additional value of the measurements is in their use for patient education illustrating that the goal of audibility has been achieved (e.g., the output of the hearing aid is above threshold and below UCL on the graph and matching the evidence-based targets). Patients need to understand why they often are not asked about their opinion of how the hearing aids sound on the day of fitting since their brain needs time to adapt to these new inputs. Accurate measurement is valuable on the day of fitting, while subjective patient impressions are valuable during the fine-tuning follow-up visit after at least 2 or 3 weeks of full-time use (all waking hours).

Real-ear aided response (also known as Speechmapping) currently is our most accurate and efficient method of verifying that the essential goal of audibility has been achieved. Verification techniques should always be dictated by the goal of the hearing aid fitting. Audibility across input levels and across the appropriate frequency range is the goal of amplification, and real-ear probe microphone techniques (RECD and REAR, in this case) provide an objective measurement of audibility. Verification (RECD and REAR) allows you to be confident that you did what you set out to do (achieved audibility across frequency and input level within the constraints of the individual's hearing loss).

REAR and other probe microphone measurements are not treatments or interventions; audibility is the treatment. The measurements we are describing allow you to know that you provided the treatment you meant to provide. Keep in mind that the outcome you are trying to achieve needs to be measured independently of verification and typically will be measured after the patient has had time to adjust to hearing aid use. Outcome typically refers to meeting the patient's goals. So, an outcome could be the individual's self-report that they are now able to communicate during family dinners, if that was one reason they came in to pursue amplification.

CALIBRATION AND LEVELING

Figure 1 provides a photo of the Verifit 2 real ear system and test box. The probe microphone assembly (Figure 1A) is stored on the side of the video screen (Figure 1B) via a magnet. You remove this and clip the probe assembly to the patient's collar when you are ready to use this. The test box (Figure 1C) is connected to the display screen. An internal speaker (Figure 1D) or external speaker (Figure 1E) can be used to deliver the input signal. You select between these two delivery mechanisms through the Set-Up menu.

Before you start to use the probe microphone test equipment for verifying hearing aid fittings and features, you need to make sure it is functioning properly. The test box and real-ear probe microphone system should be calibrated by an individual knowledgeable in instrumentation calibration. This person owns the necessary equipment to calibrate every 6 months (or sooner if there appears to be a problem). Calibrating involves making measurements with standard equipment (sound level meter) and making necessary adjustments to ensure that the equipment is measuring the correct SPLs. On a daily or weekly basis, the equipment should be leveled by the clinicians. This is an internal (relative) check on the microphones that are being used for measurement. This section will describe the leveling procedure

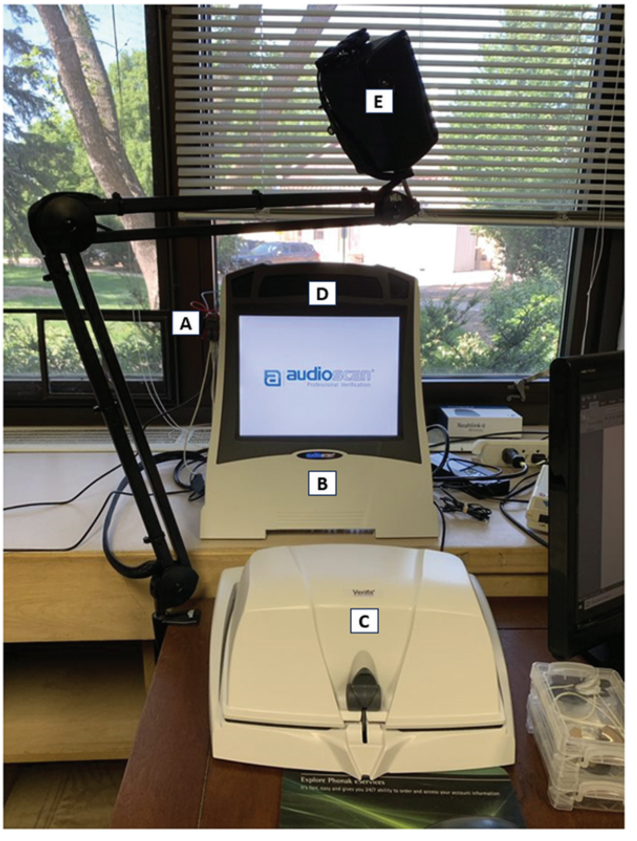

Figure 1 Audioscan Verifit 2 probe microphone and test box equipment. (**A**) Probe microphones (in dock); (**B**) display unit; (**C**) test box; (**D**) internal speaker; (**E**) external speaker.

for the probe microphone system. (Note: In the Audioscan manuals and on the Verifit screens, you will see that the term "calibration" is used for leveling; keep in mind you are not calibrating the system using these procedures, you are leveling the system).

Imagine you have just arrived in the clinic on a Monday morning and it is time to check the equipment. You will need to level (often labeled "calibrate") the hearing aid test box and the real-ear probe microphone system before you see patients. See Chapter 1 for detailed instructions.

Leveling involves playing a known sound level out of the speaker(s) and placing the two microphones that are used for measurements (in the case of the real-ear probe microphone system, this is the probe microphone and the reference microphone) as close to each other as possible so they are receiving the exact same sound (same distance from the loudspeakers). Given that the microphones are essentially in the same space, they should both measure the same SPL. If they do not, the system will adjust sensitivity internally to make a correction. This allows the system to "trust" what the reference microphone is measuring during your testing. The reference microphone will monitor the level being produced by the loudspeakers and the system will make internal adjustments to ensure that the speaker is producing the correct level of sound so that what you believe you are presenting is, in fact, the level that is being presented.

Materials needed for this activity: For these activities, you will need a real-ear probe microphone system, probe tubes.

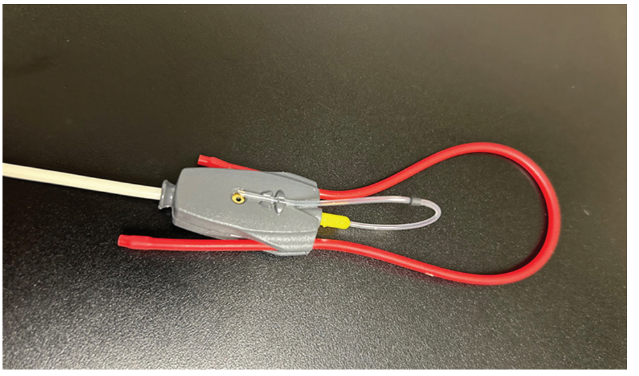

Figure 2 Probe tube (attached to the probe microphone) is placed directly over the reference microphone.

Activity 1

1. Ensure the connectors of both probe microphone assemblies are plugged into the appropriate jack on the bottom of the probe dock.
2. Right click on the mouse and select **Calibration** under **On-ear Measures** (remember, you are actually leveling).
3. Place the large end of the probe tube into the top of the probe module.
4. Position the open end of the probe tube in front of the reference microphone and press it between the two posts (see Figure 2). This is how you are bringing the two microphones (reference microphone and probe microphone) into the same space.
5. Hold the probe assembly about 18´´ (45 cm) away from and facing the loudspeaker on the top of the Verifit or facing the external/auxiliary speaker if enabled (see Figure 3). Ideally, you are holding the probe microphone assembly near where the patient's ear will be for testing.
6. Click **calibrate** on the side (left or right) that is consistent with the probe microphone assembly you are holding. The Verifit has separate probe microphones for left and right ear testing. (Reminder: you are leveling, not calibrating.)
7. Repeat the steps with the other probe microphone assembly to level the other side.
8. Compare your results to those provided in Figure 4.
9. The system has captured the measurement of the sound from the probe microphone and from the reference microphone. A difference graph is displayed and should hover around 0 (illustrating a 0-dB difference between microphones).

Helpful hint: WRECD is a RECD measurement that is made with 0.4-cc coupler (as opposed to the standard 2-cc coupler), which allows for measurements to be displayed through 16,000 Hz. This distinction is important here because WRECD data cannot be compared directly to RECD data, but we can view an equivalent RECD data using the Verifit 2 (described in Chapter 5) if the information is needed.

Materials needed for this activity: For these activities, you will need a real-ear probe microphone system, probe tubes.

Activity 2

1. Level ("calibrate") the probe microphone system using the procedure described in Activity 1. Make sure your graph is similar to the graph displayed in Figure 5.
2. Explain why the reference microphone and probe microphone must be located in essentially the same place in order for the leveling measurement to be accurate.

ESTABLISHING THE COUPLER RESPONSE PORTION OF THE REAL EAR TO COUPLER DIFFERENCE PROCEDURE

You have leveled the test box microphones (Chapter 1) and you have leveled the real-ear system microphones (Activity 2). Now you will obtain the coupler measurement that is used for

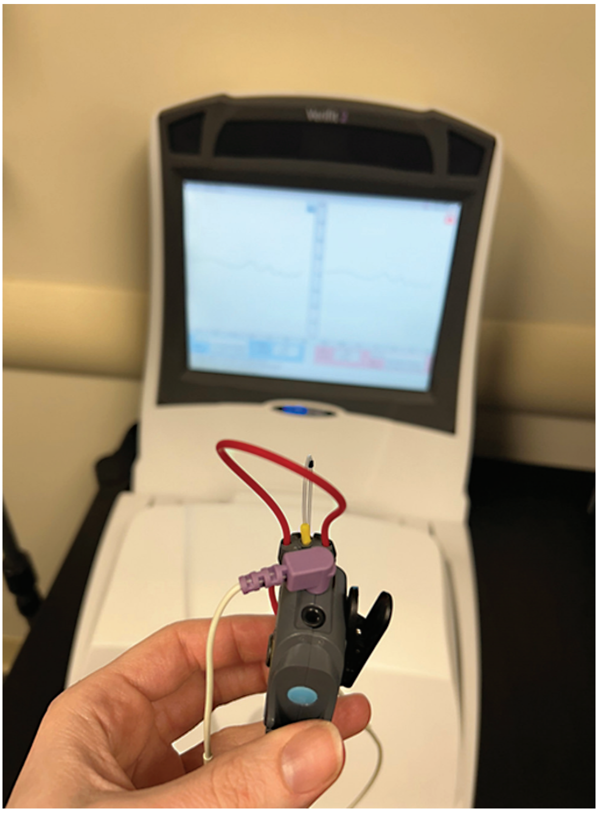

Figure 3 Positioning the probe assembly for leveling.

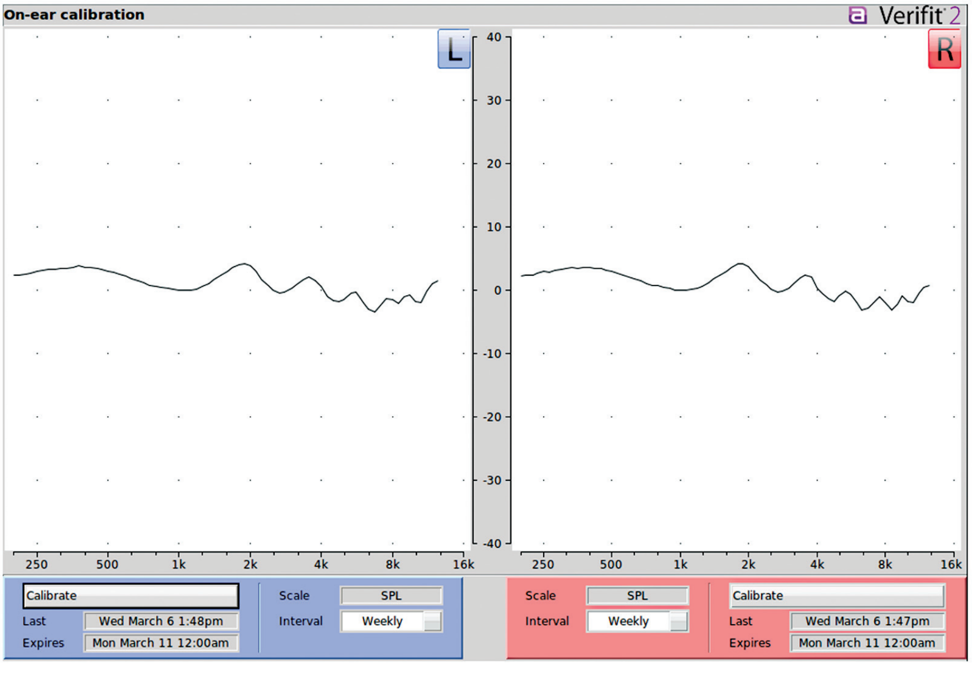

Figure 4 Probe microphone and reference microphone leveling graph.

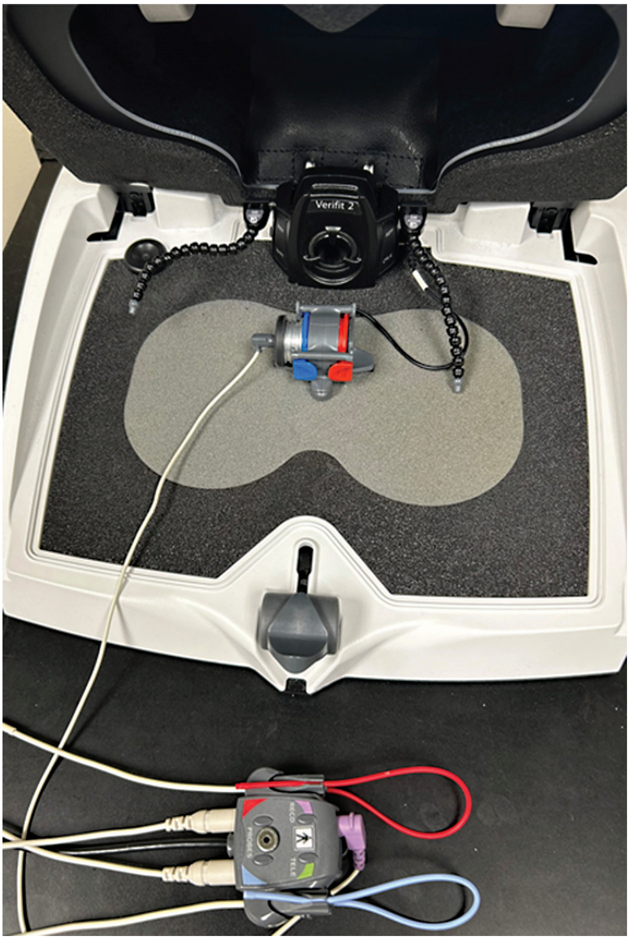

Figure 5 RECD transducer from the probe microphone assembly, attached to the left coupler in the test box.

the wideband real-ear to coupler difference (WRECD) procedure.[5]

Given that a coupler is standard and does not change, you may wonder why you need to measure the sound level that builds up in the coupler when attached to the WRECD transducer (see Figure 6) since we would not expect this to change. This is required each week to make sure that your ability to measure the coupler reliably has not been impacted (e.g., has anything damaged the coupler microphone, has the WRECD cord been damaged which could impact the delivery of sound).

Helpful hint: The system is measuring the sound measured by the probe microphone (measurement 1) and the reference microphone (measurement 2). The final display shows one line (not two). If the leveling procedure is successful, this one line will display near "0" (although the *y*-axis is not labeled, this would be dB SPL). What is producing this line at "0" dB SPL given what you know about the goal of leveling? If one sound is produced from the loudspeaker and the two microphones are measuring the exact same level of sound, if you subtract those two results, the difference would be 0 dB SPL across frequency.

Materials needed for this activity: For these activities, you will need a hearing aid test box, probe microphone assembly with WRECD transducer.

Activity 3

1. Connect the WRECD transducer to the 0.4-cc coupler using the rubber connector (thin-tube/

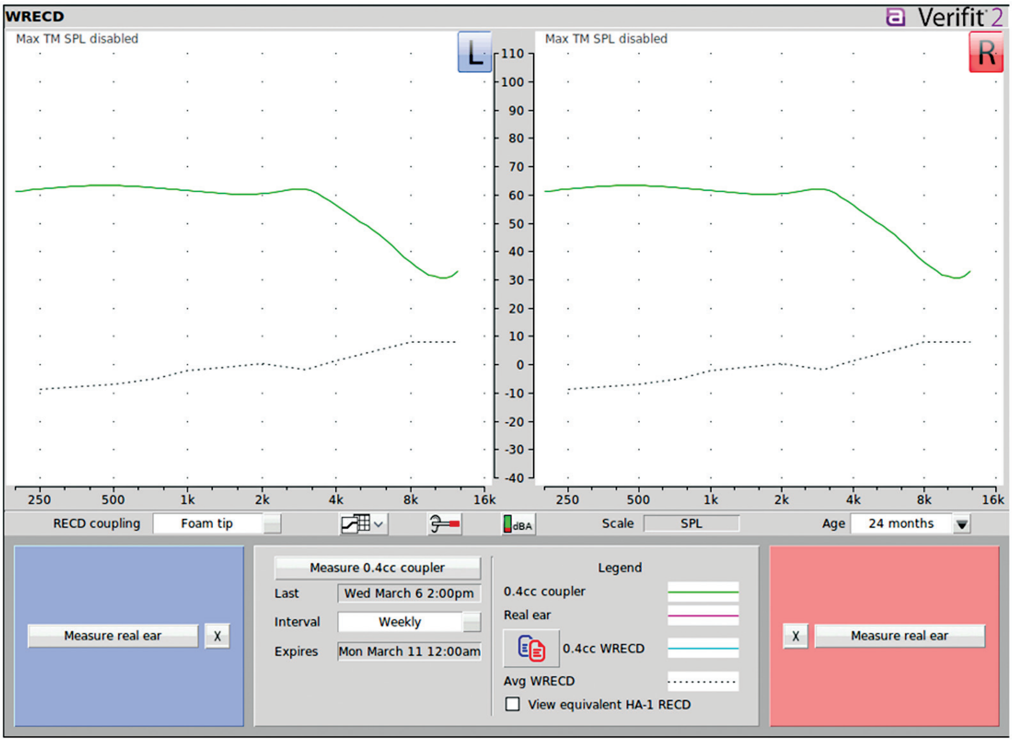

Figure 6 WRECD measurement screen.

receiver-in-canal [TRIC] adapter) that fits over the silver coupler (use the left side, see Figure 5).

2. Right-click the mouse and select Wideband RECD (**WRECD**) from the On-ear list of tests.
3. Select the on-ear coupling method you are going to use when measuring RECD (foam tip or earmold) and select the **green check mark**. The screen will show two possible measurement options: 0.4-cc coupler or real ear. You want to select **coupler** and follow the instructions to present the sound from the RECD transducer to the coupler. A test setup screen will help you to confirm that you are ready to make the measurement. Click the **green check mark** to indicate that you are ready to measure. This causes a broadband signal to be generated and measured by the coupler microphone.
4. Once the measure stabilizes, click the **green check mark** and the measurement is complete (Figure 7). This measurement is saved and serves as the "coupler" portion of the RECD measurement that you will be completing with every patient to convert the dB HL thresholds that you have obtained on the patient during the hearing test to dB SPL relative to their individual ear canal.
5. Your result will look like the measurement displayed in Figure 6 since couplers are standard.

ISSUES WITH OPEN-FIT HEARING AIDS AND REAL-EAR MEASURES

When fitting an individual with an open-fit hearing aid, the ear is indeed open. This means that the sound delivered by the hearing aid into the canal will leak out and reach the reference microphone along with the direct signal from the loudspeaker that reaches the reference microphone. One signal is the stimulus from the speaker and the other from the amplification of the hearing aid. If the system is calibrated to 60 dB and the reference microphone is receiving an intensity greater than that, it will adjust by turning down the input signal produced by the loudspeaker, thereby making it seem like the hearing aid has inadequate output. This could result in overamplification because of inaccurate measures. It is imperative when

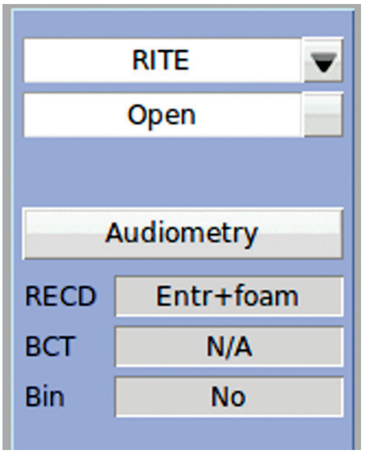

Figure 7 Indicating that you are using an open canal fitting.

fitting an individual with an open-fit style hearing aid to account for this by turning *off* the reference microphone during active measurements.

When you indicate that the instrument is "open" (Figure 7), the system turns off the reference microphone when you are completing Speechmapping. An "open" fitting could include an open dome coupling or an earmold that has a large vent. If "open" is selected, you will be prompted to **equalize**. Equalization is a leveling procedure for open-fit hearing aids and, after completion, the reference microphone is turned off for the rest of the measurements. When you equalize, you need to turn off or mute the hearing aid (you can do this manually or in the software if the hearing aid is connected to the manufacturer's fitting software). If you do not turn off the hearing aid, the measurement will already be inaccurate because the hearing aid amplification could leak out of the ear and reach the reference microphone. Once equalization is complete, remember to turn the hearing aid back on for your measurements!

PATIENT PREPARATION

The patient should be seated facing the loudspeaker (internal or external speaker) when you are ready to collect real-ear probe microphone measures. Next you want to look in the ears with an otoscope to make sure the ear is not occluded with ear wax. Ear wax can block the probe tube and it can block the hearing aid receiver (loudspeaker).

Be sure to explain the procedure to the patient. Let them know that you will be placing a small tube in their ear and taking a measurement. The soft tube usually tickles and might make them cough. If they feel a pinch, they should let you know so that you can move the probe microphone. Importantly, you can tell the patient that the tube cannot injure them. In fact, if the probe microphone touches the eardrum, typically the person will hear a thud rather than experience pain. Patients want to be reassured that the procedure cannot result in injury even if it feels a bit uncomfortable.

For a hearing aid fitting, the first measure you will do is the WRECD and then you will move on to the REAR. Chapter 5 will familiarize you with these measures. Now that you have leveled your equipment and captured the coupler portion of the WRECD measurement, you are ready to verify and fine-tune your patient's hearing aids.

Troubleshooting

When using the Verifit system, you may see that a hearing aid is producing no or low gain. You will want to check a few things when troubleshooting. Always assume something is amiss in your setup. Here are some troubleshooting tips that commonly solve the issue mentioned earlier.

1. Is the probe microphone connected to the probe assembly? (It can come loose.)
2. Is the probe microphone in their ear?
3. Is the hearing aid in the ear with the probe microphone?
4. Is the hearing aid on?
5. Is the probe microphone in the correct ear?
6. Is the probe microphone clogged with cerumen?
7. Is the sound coming out of the correct loudspeaker (internal vs. external)?
8. If you are using the external speaker, is it plugged in?
9. Do you have the test set to "test box" so the sound is coming out of the speaker in the test box and not out of the loudspeakers used for real ear measures?

CONCLUSION

Now that you have leveled the equipment and measured the coupler response to a known signal, you are ready to use the probe microphone system to help you fit, evaluate, and troubleshoot hearing aids.

CONFLICT OF INTEREST
None declared.

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