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Comparing Probe Tube Placements and Frequency Averaging in the Ear Canal Up To 10 kHz

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Background

Real-ear measurement using a probe tube microphone has become a routine procedure for assessing hearing aid output and gain levels in the user's ear. Traditionally, hearing health care professionals are encouraged to place the probe tube within 6 mm of the eardrum, and 2 mm of repeated measurements.[1] This ensures that the level of sound recorded in the ear canal is within 2 dB of the true level at the eardrum and 2 dB of the level of recordings taken at the same location up to 6 kHz. Until now, the upper frequency cut-off has rarely been a concern for clinicians because past hearing aid technologies have not typically amplified frequencies above 6 kHz.

Extended-bandwidth products are becoming more common in today's profession. Some commercial hearing aids now amplify as high as 10 kHz.[2] Prescriptive methods like NAL-NL2 and CAM2A provide gain targets up to 8 and 10 kHz, respectively,[3] and verification systems such as Audioscan Verifit 2 advertises hearing aid verification up to 12.5 kHz. While these advancements bring the potential for improved patient outcomes, they also bring considerations for clinicians.

A shallow probe tube placement can distort extended bandwidth responses due to interactions between standing waves and the location of the probe tube. Standing waves cause a level reduction at various places in the ear canal. If the probe tube is placed too far from the eardrum, standing waves create a greater level reduction and the measurement becomes less accurate.[4] This is primarily a concern for higher frequencies, as even 2 mm differences can cause level changes of 2 dB or more. If the difference between the level at the probe tube and the eardrum exceeds 2 dB, then the clinician is not measuring the true output of the instrument at the eardrum.

Standing waves may also be impacted by frequency-averaging features offered in some verification products. Third-octave bands average a third of an octave's spectra to a single frequency and some verification systems (such as Audioscan Verifit 2) exclusively measure sound levels using this technique. If a third-octave band is wider than the standing wave notch, then the effect of the standing waves on real-ear-measurement may become obscured. Some systems (such as the Interacoustics Affinity and Otometrics Aurical) offer narrowband averaging relative to third-octave band analysis. These techniques may be more sensitive to standing wave measurements in the ear canal, and therefore may be more accurate measuring high frequency responses in the ear canal.

In this report, we present a case of extended bandwidth real ear measurement using the probe tube method. We recorded a white noise signal up to 10 kHz in an ear canal, using four insertion depths, with third-octave and twenty-fourth-octave band averaging. We describe the repeatability and accuracy of level differences in the ear canal associated with changes in probe tube insertion depth and frequency-averaging bandwidths. We predicted that extended bandwidth frequencies would become less repeatable as the probe tube moved further away from the eardrum, and that shallower measurements would become less predictive of the level at the eardrum. We also predicted that a narrowband analysis would be more sensitive to standing waves.

Procedure

A female adult participant who reported normal hearing and middle ear function participated in this case study. Sound levels were only measured in her left ear. Probe tube placement closed resemble the method described by.[5] A probe tube was marked at 4 lengths (Figure 1) from the open end of the tube. It was marked at 28 mm (the general guideline for female probe tube measurements) and an exceptionally deep placement (at 30 mm) so the probe tube would be closer to the eardrum. It was also marked for two shallower insertion depths (at 26 mm and 24 mm), so that standing waves would become more apparent.

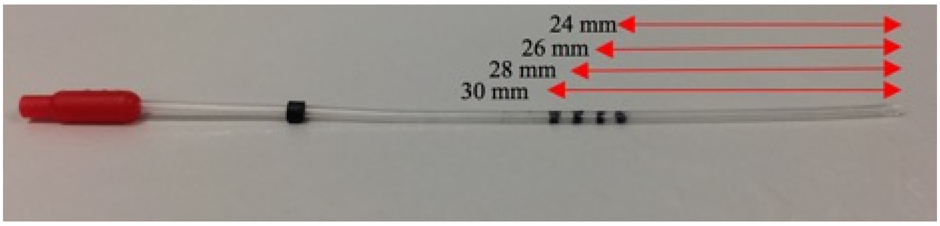

Figure 1. The probe tube was marked at four lengths to indicate the insertion depth distance from the intra-tragal notch.

The probe was first inserted into the ear canal using the deepest insertion depth, followed by a foam insert transducer. Correct probe placement was verified by observing the insertion depth mark of probe tube at the inter-tragal notch. White noise was presented and recorded at 82 dB SPL. The probe was retracted by 2 mm using the insertion depth marks, and the stimulus was presented again. The procedure was repeated until the stimulus was presented at the shallowest insertion depth, after which both the probe tube and foam tip were removed. This procedure was performed twice.

This procedure yielded a total of eight measurements (two test repetitions and four insertion depths per repetition). Recordings were saved to SpectraPlus sound analysis software and analyzed using third-octave and twenty-fourth-octave bands at 15 frequencies (0.4, 0.5, 0.63, 0.8, 1, 1.25, 1.6, 2, 2.5, 3.15, 4, 5, 6.3, 8, and 10 kHz).

Results

Repeatability

We defined repeatability as how much the degree to which recordings varied between the first and second measurement for the same insertion depth using the same frequency-averaging bandwidth. It was measured by calculating the absolute test-retest level difference between the first and second measurement at each frequency, and described against the 2 dB criterion. The results for third- and twenty-fourth-octave bands are illustrated in Figures 2 and 3, respectively.

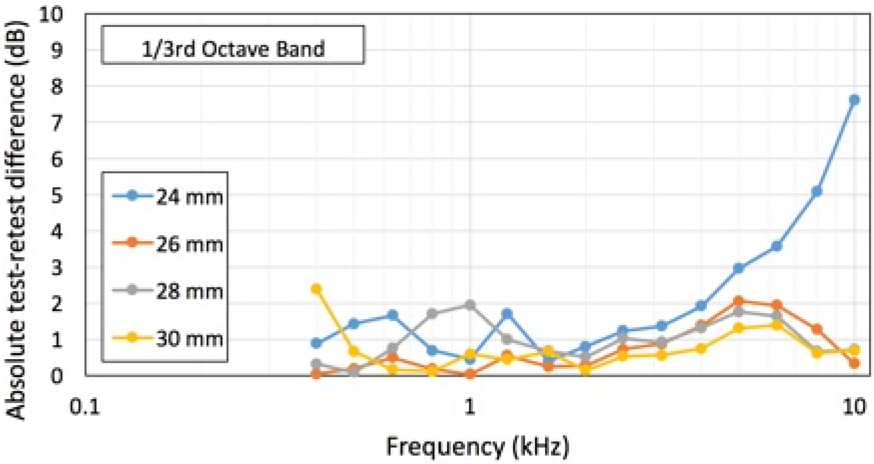

Figure 2. Test-retest repeatability measured as the absolute difference in dB between the first and second recordings for each insertion depth using third-octave bands.

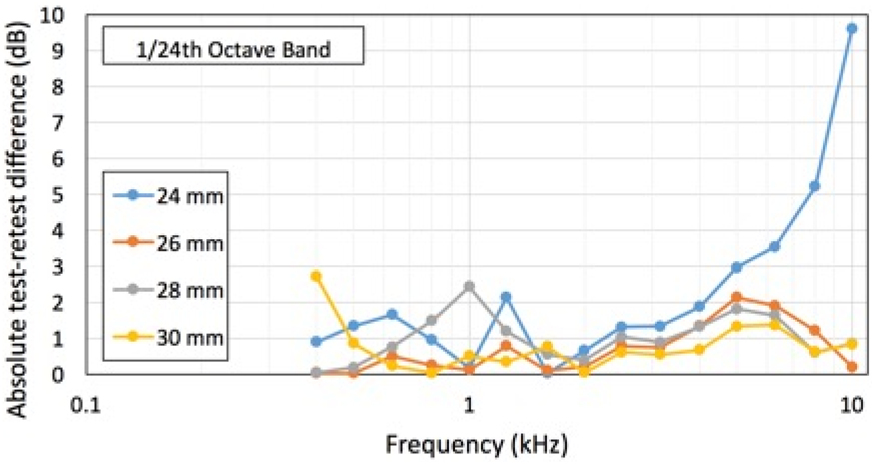

Figure 3. Same as Figure 2, except using twenty-fourth-octave bands.

Using third-octave bands, test-retest differences at the 24 mm insertion depth fell below 2 dB from 0.4–4 kHz. At 5 kHz, the test-retest difference exceeded 2 dB, and increased with magnitude as the measurement frequency increased. At the 26 mm insertion depth, test-retest differences fell within 2 dB from 0.4–10 kHz, except at 5 kHz for which the test-retest difference slightly exceeded 2 dB. For the 28 mm insertion depth, test-retest differences fell below 2 dB from 0.4–10 kHz. For the 30 mm insertion depth, test-retest differences fell below 2 dB from 0.5–10 kHz. At 0.4 kHz, the test-retest difference was about 2.5 dB.

The trend was generally the same using twenty-fourth-octave bands barring a few exceptions. For example, the test-retest difference at 1.25 kHz slightly exceeded 2 dB at the 24 mm insertion depth. Additionally, the test-retest difference at 1 kHz slightly exceeded 2 dB at the 28 mm insertion depth.

Accuracy

We defined accuracy as how closely recordings resembled the sound level at the eardrum. The 30 mm insertion depth was selected as the reference point because it was the closest measurement recorded relative to the eardrum. Accuracy was measured by subtracting the average response measured at the 30 mm insertion depth from the average response measured at the 24 mm, 26 mm, and 28 mm insertion depths for third- and twenty-four octave bands. This allowed us to observe standing wave effects as the probe tube with removed. This also allowed a comparison between third- and twenty-fourth-octave band analyses with the expected absolute magnitude differences removed. The resulting values are again described against the 2 dB criterion. The results for third- and twenty-fourth-octave bands are illustrated in Figures 4 and 5, respectively.

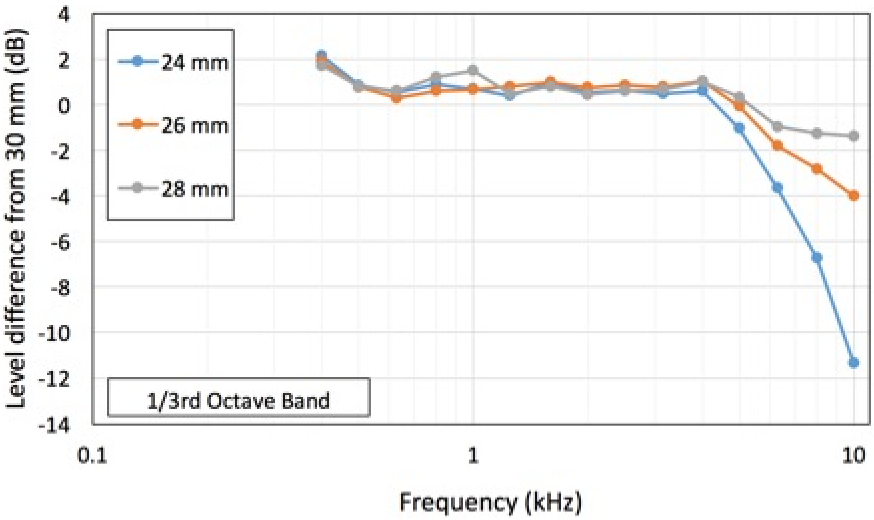

Figure 4. Averaged spectra measured as a difference from the 30 mm insertion depth in dB for each insertion depth using third-octave bands.

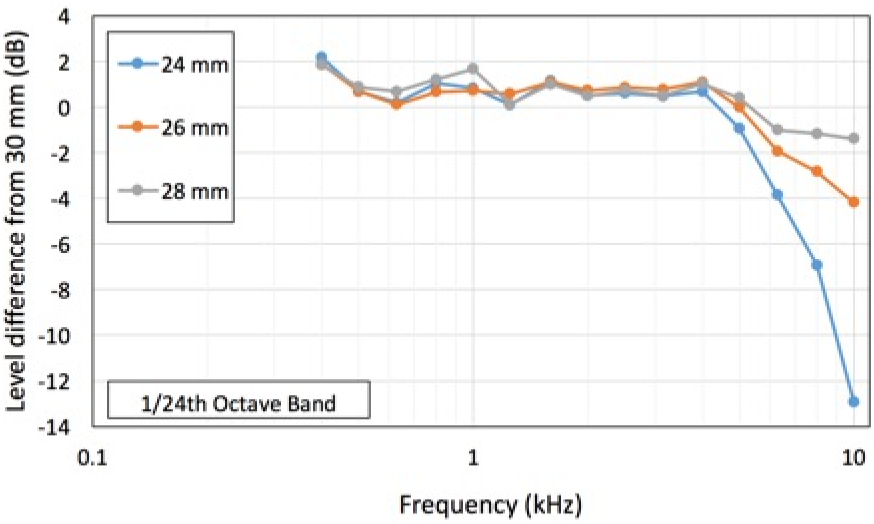

Figure 5. Same as Figure 4, except using twenty-fourth-octave bands.

Using third-octave bands, the level of the 24 mm insertion depth was within 2 dB of the level of the 30 mm insertion depth up to 5 kHz. At 6.3, 8, and 10 kHz, the level was attenuated relative to the 30 mm insertion depth by 3.9, 6.9, and 12.9 dB, respectively. The level of the 26 mm insertion depth was within 2 dB of the 30 mm insertion depth up to 6.3 kHz. At 8 and 10 kHz, the level was attenuated relative to the 30 mm insertion depth by 2.8 and 4.2 dB respectively. The level of the 30 mm insertion depth was within 2 dB of the level of the 30 mm insertion from 0.4–10 kHz. At 0.4 kHz, the level of each insertion depth exceeded the level of the 30 mm insertion by approximately 2 dB.

The trend was generally the same using twenty-fourth-octave bands. Levels at each insertion depth for each frequency were typically within 2 dB of those measured using third-octave band averaging, with the majority of frequencies deviating by no more than 0.4 dB.

Discussion

For measures of repeatability, we predicted that extended bandwidth frequencies would become less repeatable as the probe tube was moved further away from the eardrum. This was observed in this report. Minimal test-retest differences were observed up until 4 kHz, which is consistent with previous evaluations.[6] In the frequency range above 4 kHz, at least for the shallowest insertion depth, test-retest differences fell above 2 dB, with the magnitude of the difference increasing as frequency increased. This increase is attributed to the interaction of the probe tube placement with standing waves. Test-retest differences in the extended bandwidth decreased as the probe tube moved closer to the eardrum. While they were consistently below 2 dB for the 26, 28, and 30 mm insertion depths, it does not imply accurate measurement as they may have reliably measured the standing wave attenuation and not the true level at the eardrum.

For measures of accuracy, we predicted that the shallow probe tube placements would underestimate levels recorded near the eardrum, particularly for high frequencies. This was also observed in this report. The 24 mm and 26 mm insertion depth recordings were predictive of the level recorded at the 30 mm insert up to 5 and 6.3 kHz, respectively. The 28 mm insertion depth was within 2 dB of the level recorded at the 30 mm insertion depth at all frequencies. Furthermore, the attenuation of higher frequencies was greater for shallower insertion depths compared to deeper insertion depths. This suggests that the probe tube approached the standing wave minimum as it was moved further from the eardrum. We also observed a 2 dB overestimate at 0.4 kHz between the shallower insertion depths and 30 mm insertion depth. Low frequency measurement accuracy may be reduced due to slit leak venting. Given that the 30 mm insertion depth was the first recording in the procedure, it is possible that the foam transducer was not fully expanded. This enhances the opportunity to observe slit leak venting in the 30 mm insertion depth recording, relative to shallower recordings in which the transducer had fully expanded.

The hypothesis that a narrowband analysis would be more sensitive to standing waves was not supported. Measures of repeatability and accuracy using third- and twenty-fourth-octave bands differed by no more than 2 dB in most cases, suggesting that twenty-fourth-octave bands obscure the standing waves equally as much as third-octave bands. Further studies may choose to investigate a narrower-band analysis in which fewer frequencies are averaged to a single frequency.

There are some limitations to this report. Although the 30 mm insertion depth represented the reference point, it is possible that it did not represent the true level at the eardrum. Therefore, there may be more measurement error to be considered. Additionally, the procedure used here only applied to a single adult female ear canal. Ear canal acoustics differ in other individuals due to anatomical differences. Furthermore, the recommended insertion depth for males is 30 mm.[7] Rather than generalizing the findings of the current report to others, it should be considered as a demonstration of level differences associated with insertion depth deviations as little as 2 mm.

Conclusion

The advent of extended-bandwidth products is indicative of technological advancement and potential improvements for patient outcomes. However, it warrants the need to revisit the probe tube measurement procedure. We have demonstrated a case in which shallow probe tube placements in the ear canal underestimated levels above 6.3 kHz at the eardrum by 2 dB or greater. Both third- and twenty-fourth-octave bands were equally sensitive to these level reductions. The 28 mm insertion depth was predictive of the level of the 30 mm insertion depth. This reinforces the need for clinicians to be wary of probe tube insertion depth, if measuring the true level at the eardrum is the goal.

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