Acoustic Variability of Occluded Earbuds in Receiver-in-the-Canal Hearing Aid Fittings

Courtney Coburn, Au.D., Joyce Rosenthal, M.A., B.S.E.E., Kenneth Kragh Jensen, Ph.D.

Starkey Hearing Technologies

Introduction

Receiver-in-the-canal (RIC) hearing aids are commonly coupled with stock earbuds in clinical practice. These non-custom earpiece options have become increasingly popular among clinicians and patients, as they may offer convenience and comfort, as well as cosmetic and acoustic advantages over traditional custom earmolds (Kuk, 1991; Taylor, 2006). Manufacturers typically offer a variety of earbud styles, which clinicians may use to accommodate varying degrees of hearing loss: from open styles for mild losses, to occluding styles for moderate to severe losses *(Figure 1)*.

Figure 1. Commercially available stock earbud styles offered by Starkey Hearing Technologies. From left to right: *Open Earbud, Occluded Earbud, Power Earbud.*

However, the differences in acoustic effects of these various earbud styles are not well-characterized and may be highly variable. Specifically, the degree to which various earbud styles influence the acoustics of the direct path of a sound source *into* the ear canal, as well as how much of the amplified acoustic signal leaks *out* of the ear canal, is not fully characterized *(Figure 2)*. Although both acoustic pathways are important, the low-frequency leakage of the amplified sound path may have a drastic negative impact on a hearing aid fitting. This uncharacterized acoustic leakage is problematic, as the use of an occluded earbud to extend the fitting range of a hearing aid assumes that:

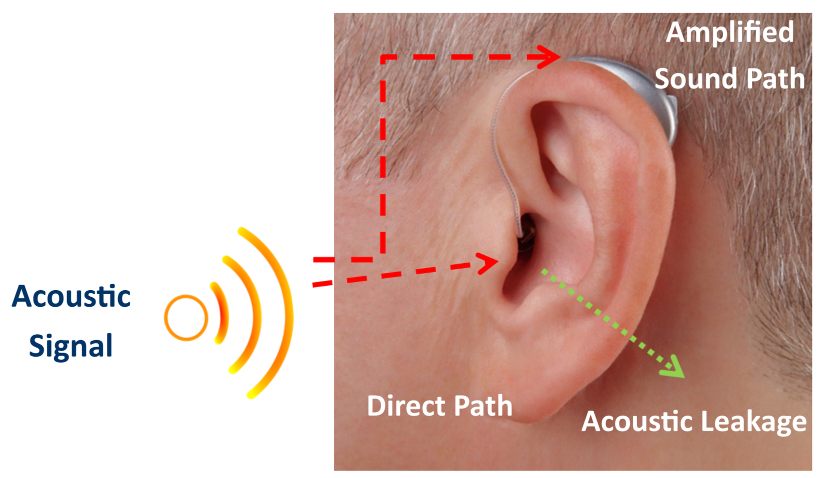


Figure 2. The pathways of an acoustic signal to the tympanic membrane. The signal may be directed through the amplified sound path, or through the direct path to the ear. Leakage of the acoustic signal out of the ear is expected, and the amount of leakage may be related to earbud style.

(1)The fit of the earbud is sufficiently tight to achieve true occlusion in the ear canal, and thus, allows for the predicted amount of low frequency amplification, and

(2) The fit of the earbud is acoustically consistent across multiple hearing aid fittings.

If either of these assumptions proves incorrect for any particular hearing aid fitting, the accuracy of the prescribed gain and the sound quality of the fitting may be compromised.

Given the unknown acoustic effects of various stock earbud options, the purposes of this study were as follows:

- To characterize the relative acoustic leakage of stock earbud styles used in receiver-in-the-canal hearing aid fittings.
- To assess the implications of selecting stock earbud styles for clinical hearing aid fittings, particularly in terms of the validity and reliability of such fittings on an individual patient basis.

Methods

- Eight adults with normal hearing participated in this study (5 males, 3 females).
- Two clinically-experienced audiologists selected the appropriate earbud size for each participant's left ear. Earbud size options are displayed in *Table 1*. The audiologists were asked to select the earbud size based off otoscopic examination, judgment of the earbud fit in the ear canal, and clinical experience. The audiologists were blinded from each other's size selections.

	Open Earbud	Occluded Earbud	Power Earbud
Small	5mm	5mm	8/10mm
Medium	8mm	8mm	10/12mm
Large	10mm	10mm	12/14mm

Table 1. Available sizes per each style *(open, occluded, power)* of earbud.

- When a discrepancy existed between the size selections of the audiologists, a third audiologist also selected an earbud size for the participant. The earbud size most frequently selected between the three audiologists was used for the study.

Methods, continued

- A custom hole was drilled into each **occluded** and **power** earbud to allow the Verifit probe microphone to be routed through the earbud without introducing additional acoustic leakage *(Figure 3)*.
- In addition to the use of stock earbuds, a custom occluding earmold was made for each participant's left ear. A custom hole was also made in each earmold to allow the probe microphone to be routed through without introducing additional acoustic leakage *(Figure 4)*.
- Each probe tube (including those routed through occluded and power earbuds) was tested with the Verifit to ensure functionality. Specifically, a 75 dB SPL pink noise was played through the Verifit soundfield speaker and measured through each probe to ensure that the probe was not pinched or blocked.
- Real-ear probe microphone measurements were collected on each participant by a clinically-experienced audiologist:
  - Each participant was seated directly in front of the soundfield speaker, which was placed approximately 29 inches from the center of each participant's head. A standard (non-routed) probe microphone was inserted into the participant's left ear. Otoscopic examination verified proper insertion depth, with probe tube placement 2-5mm from the tympanic membrane.
  - The acoustic noise floor was measured for each participant with the probe module on the ear and the probe microphone in the ear. Noise floor measurements were used to verify the validity of the acoustic leakage measurements.

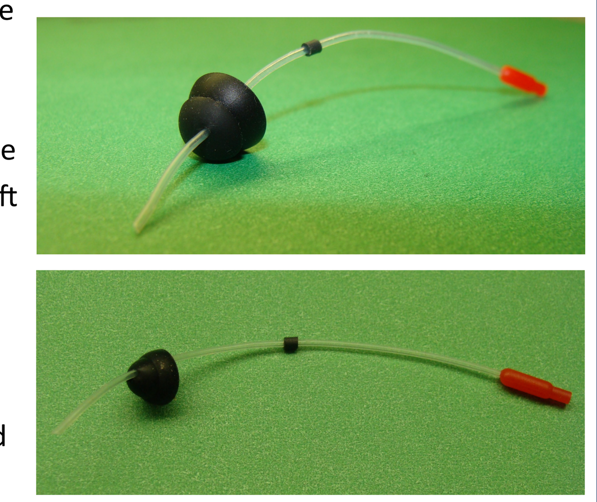


Figure 3. Probe tubes were routed through a custom-drilled hole in all occluded and power earbuds to ensure that the measurement system did not introduce additional acoustic leakage around the earbud seal within the ear canal.

Amplified Sound Path Measurements:

- A Starkey Xino i110 RIC 312 with a 50 dB gain receiver was used for all measurements.
- A hearing aid-generated, broadband tone complex with a fundamental frequency of 50 Hz, including all harmonics up to 8 kHz, was used as the stimulus for all measurements *(Figure 5)*. Using the hearing aid as the sound source allowed for isolated measurements of the acoustic leakage without interference from the direct path contribution of a soundfield source.
- Probe-microphone measurements recorded the sound pressure level inside of each participant's ear canal using the 'Speech-live' stimulus option on the Audioscan Verifit Speechmap screen for each condition: *open earbud, occluded earbud, power earbud,* and *custom occluding earmold.*

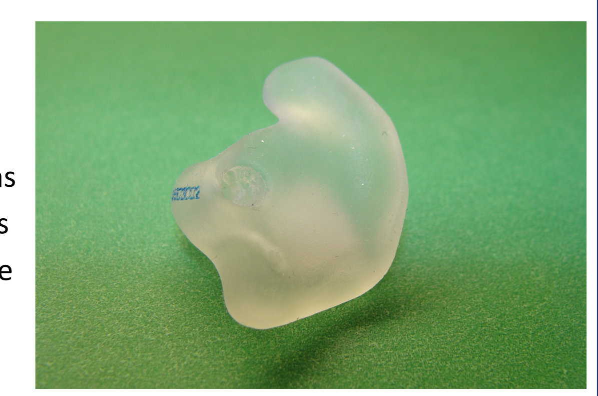


Figure 4. A custom occluding earmold was made for each participant's left ear. A custom hole was drilled into the earmold to allow the probe tube to be routed through without introducing additional acoustic leakage around the earmold seal within the ear canal.

- *Custom occluding earmold* measurements were collected to establish a reference condition. It was expected that the custom mold condition would result in the least amount of acoustic leakage relative to the earbud conditions. Measurements collected from each participant were normalized relative to the participant's custom mold condition.
- Measurements were collected once (Trial 1) for all participants. Additional measurements (Trial 2) were collected from a subset of participants (n=5). Prior to Trial 2 measurements, the receiver and earbud were taken out of the ear and placed back in the ear by the same audiologist.

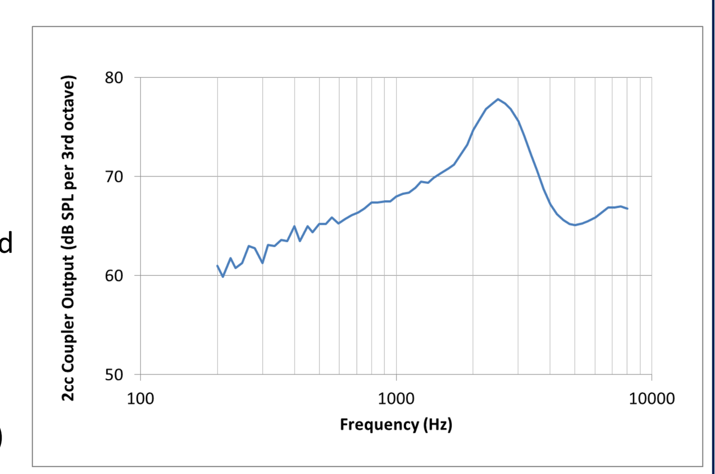


Figure 5. The recorded output of the hearing aid-generated, broadband tone complex in a 2cc coupler.

Results

(1) Effects of earbud style on low-frequency acoustic leakage

A one-way analysis of variance (ANOVA) was conducted to compare differences in the amount of acoustic leakage across the three earbud conditions. Results revealed a significant difference in acoustic leakage between conditions ($F(1,22)$ = 7.711, p = .01). Bonferroni-corrected paired t-tests were performed as post-hoc analyses to evaluate differences in acoustic leakage between each of the three conditions. Results revealed a significant difference in the acoustic leakage between the open earbud (M= -19.23, SD= 3.55) and power earbud (M= -8.52, SD= 6.83) conditions (p = .02), and the occluded earbud (M= -20.12, SD= 9.91) and power earbud (M= -8.52, SD= 6.83) conditions (p = .01). There was not a significant difference between the open earbud and occluded earbud conditions (p > .05).

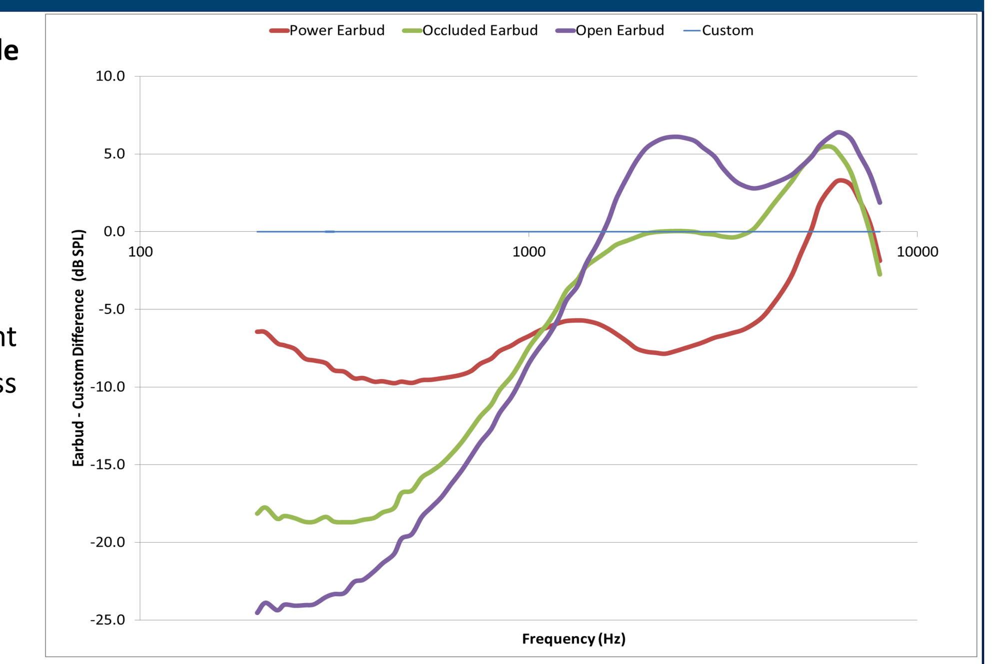
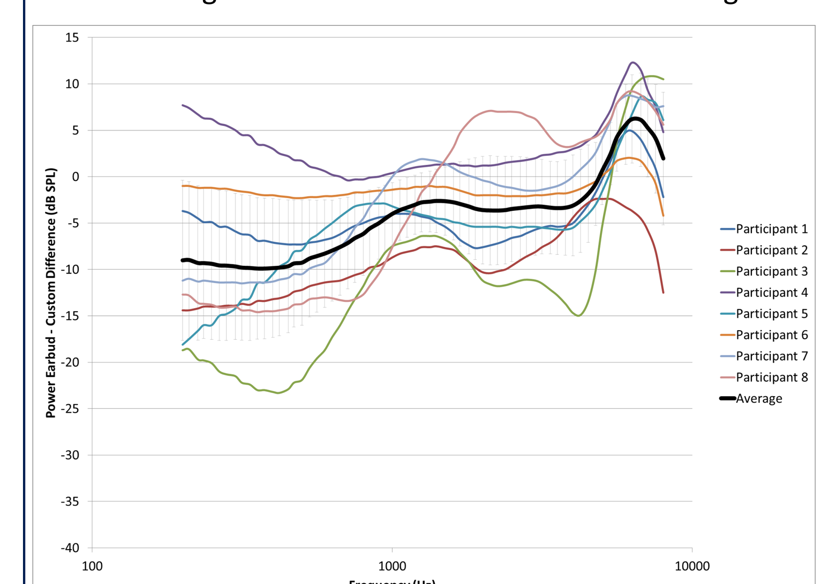
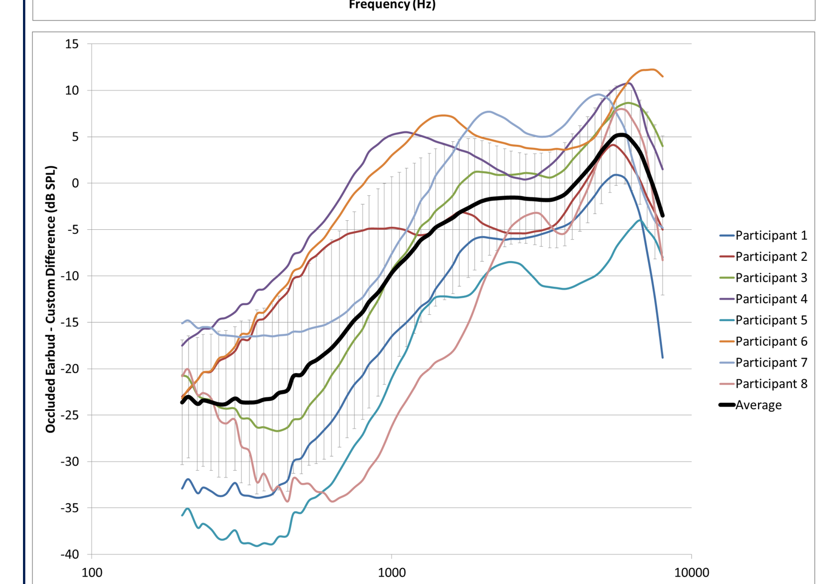


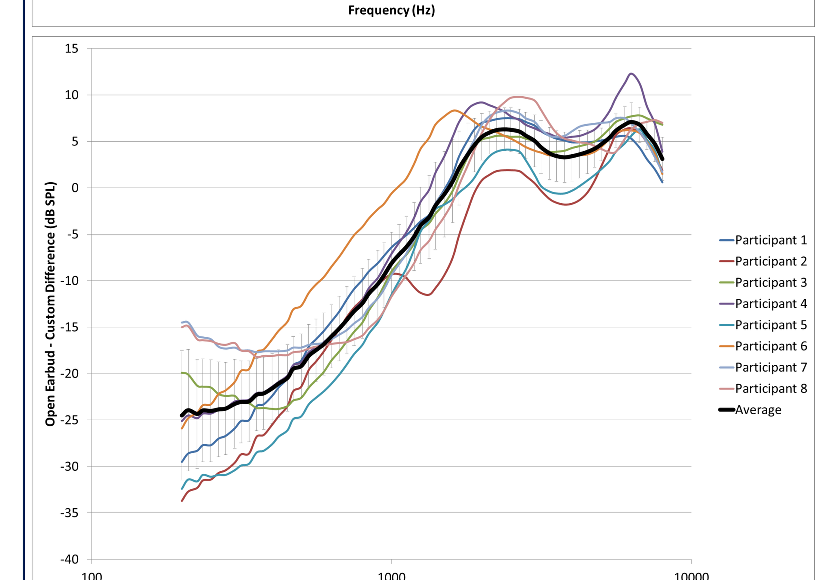
Figure 6. The average acoustic leakage for all participants (n=8) across trials for each earbud condition relative to the custom earmold condition. Relative to the custom occluding mold, the acoustic leakage is greatest for the open earbud condition, and smallest for the power earbud condition.

(2) Variability of acoustic leakage across earbud conditions

In order to evaluate the variability in acoustic leakage across the three earbud conditions, a pairwise F-test of variance equality was conducted. Results indicated a significant difference in variance between the open earbud and occluded earbud conditions ($F(1,7)$= 7.79, p = .01). Results indicated no significant difference in variance between open earbud and power earbud conditions ($F(1,7)$= 3.71, p > .05), or between the occluded earbud and power earbud conditions ($F(1,7)$= 2.10, p > .05).







Figures 7-9. The acoustic leakage of all participants (n=8) in the power, occluded, and open earbud conditions, respectively. The thick black line in each condition displays the average acoustic leakage for all participants, with +/- 1 standard deviation displayed by the error bars.

Results, continued

(3)Variability of acoustic leakage across trials

A two-way repeated measures analysis of variance (RM-ANOVA) was conducted to evaluate differences in acoustic leakage between trials and earbud conditions for a subset of participants (n=5). Results indicated that there was a significant difference in acoustic leakage between conditions ($F(1,2)$= 6.51, p = .006). There was no significant difference in acoustic leakage between trials ($F(1,2)$= .09, p > .05), or effect of trial by condition ($F(1,2)$= .84, p > .05).

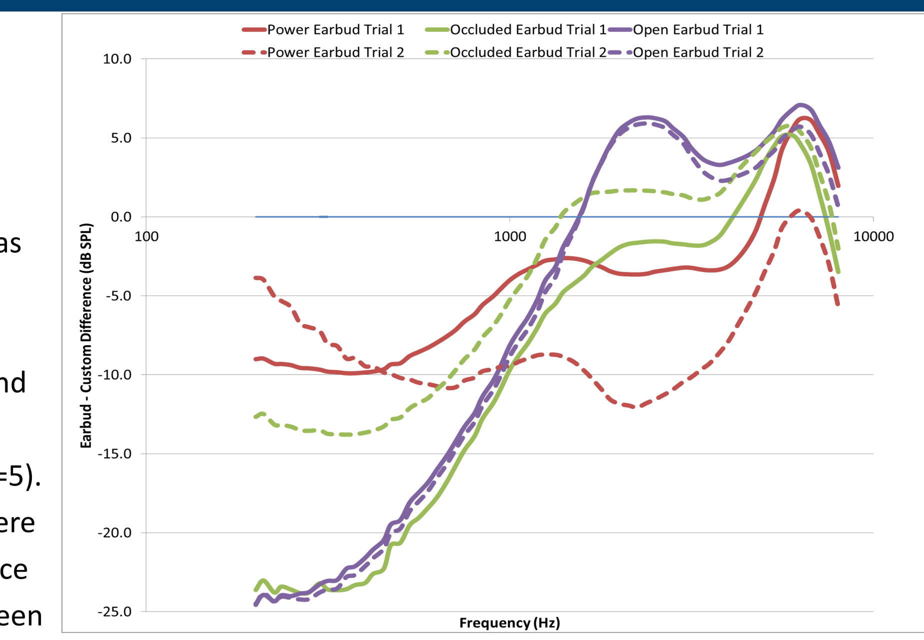


Figure 10. The average acoustic leakage of all participants (n=5) across conditions in Trial 1 (solid lines) and Trial 2 (dotted lines).

Summary and Conclusions

- Results suggest that although the acoustic behavior of open earbuds is consistent and as expected across individuals and across trials, the acoustic behavior of occluded and power earbuds is not predictable. Specifically:
  - Occluded earbuds, in most cases, behave acoustically similar to open earbuds for frequencies below 1,000 Hz. The use of the word "occluded" to describe an earbud may describe only the physical, unvented style of the earbud, not necessarily the amount of occlusion it is expected to achieve in the ear.
  - Power earbuds may achieve a substantially greater amount of occlusion in the ear canal relative to open and occluded earbuds. However, power earbuds may not necessarily be an equivalent substitute for a custom occluding mold in terms of achieved occlusion.
  - Occluded earbuds show a significant amount of variability across individuals.
  - Results warrant further investigation of acoustic variability across trials with a larger sample size. However, current results suggest that the amount of expected occlusion should never be presumed for any individual when using stock earbuds.

Clinical Relevance:

- This investigation points to the need for clinicians to be prudent in the selection and use of stock earbuds in hearing aid fittings. Specifically:
  - The use of an occluded or power earbud for extending the fitting range of a hearing aid may or may not be acceptable and must be determined on an individual patient basis.
  - Acoustic options must be correctly selected by the clinician in a manufacturer's fitting software in order to most accurately prescribe gain and hearing aid settings for any given fitting. The failure to do so may result in inappropriate gain prescriptions.
  - The acoustic effects of occluded and power earbuds should not be assumed between patient visits. In the case of a patient complaint of inappropriate gain at a follow-up appointment, earbud style cannot be discounted as a potential contributing factor without investigation.
  - Real ear probe-microphone measurements must be performed to ensure prescribed gain and hearing aid settings are appropriate for any given fitting.

References

Dillon, H. (2001). *Hearing aids*. Thieme.

Kuk, F.K. (1991). Perceptual consequences of venting in hearing aids. *British Journal of Audiology, 25*(3), 163-169.

Taylor, B. (2006). Real-world satisfaction and benefit with open-canal fittings. *The Hearing Journal, 59*(11), 74-76, 78, 80-82.