Specific Coupling Can Affect Perceived Loudness in Insert Earphones

Kristen L. D'Onofrio M.A., Stephen D. Ambrose, and Todd A. Ricketts, Ph.D.
Department of Hearing and Speech Sciences, Vanderbilt University, Nashville, TN

INTRODUCTION

Previous data have demonstrated that to provide the same loudness for low frequency sounds, lower in-ear sound levels are necessary for open ear listening than for occluded earphones (Keidser et al, 2000). The purpose of this study was to evaluate the relative level of narrowband signals delivered by two fully occluding commercial insert earphones and a new modification of these devices when matched for loudness in listeners with normal hearing. The modification consisted of a membrane covered vent, which was designed to reduce the occlusion effect while reducing the loss of low frequency output associated with venting (Figure 1). In addition, the effect of the modification on the frequency response was also evaluated. It was hypothesized that the modified earphone would require a lower level to provide the same loudness in comparison to the unmodified condition.

METHODS

Participants: 18 adult participants with normal hearing (16 female, 2 male) aged 22-31 years (mean age 25.5 years).

Adults were tested in a sound-treated test booth in the Dan Maddox Hearing Aid Research Laboratory at Vanderbilt University. Inclusion criteria were normal hearing as measured by screening, normal cognitive function as determined by self report, and the ability to complete the study procedures.

Test Methods: A loudness balancing procedure modeled after that used by Keidser et al. (2000) was used to match the perceived loudness of modified and unmodified versions of two commercially available earphone models. Test stimuli consisted of low-passed (100 Hz) music and pulsed 80 Hz, 500 Hz, and 3000 Hz pure tones. A signal was presented through one earphone (~3 seconds), followed by a brief pause (~1 second), followed by the same signal presented through the other earphone (~3 seconds). Listeners indicated to the experimenter whether to increase or decrease the level of the signal in the second earphone in order to match the two signals for loudness. Step size started in 4 dB increments and was reduced to 1 dB after two reversals. After four additional reversals, the signal level was recorded as the average of the last two reversals.

A balanced crossover design was used for each comparison. Specifically, presentations included both left ear and right ear presented first, and modified and unmodified earphones presented first, to offset any ear or order effects. In addition, the modified earphone was evaluated on both the left and right ear and the data were averaged to account for any differences in hearing sensitivity between individual participants' ears. Furthermore, loudness balancing was completed between identical earphones (modified or unmodified) in order to specifically measure order effects and possible ear preference. For any given trial, the earphone brand was the same between ears.

RESULTS

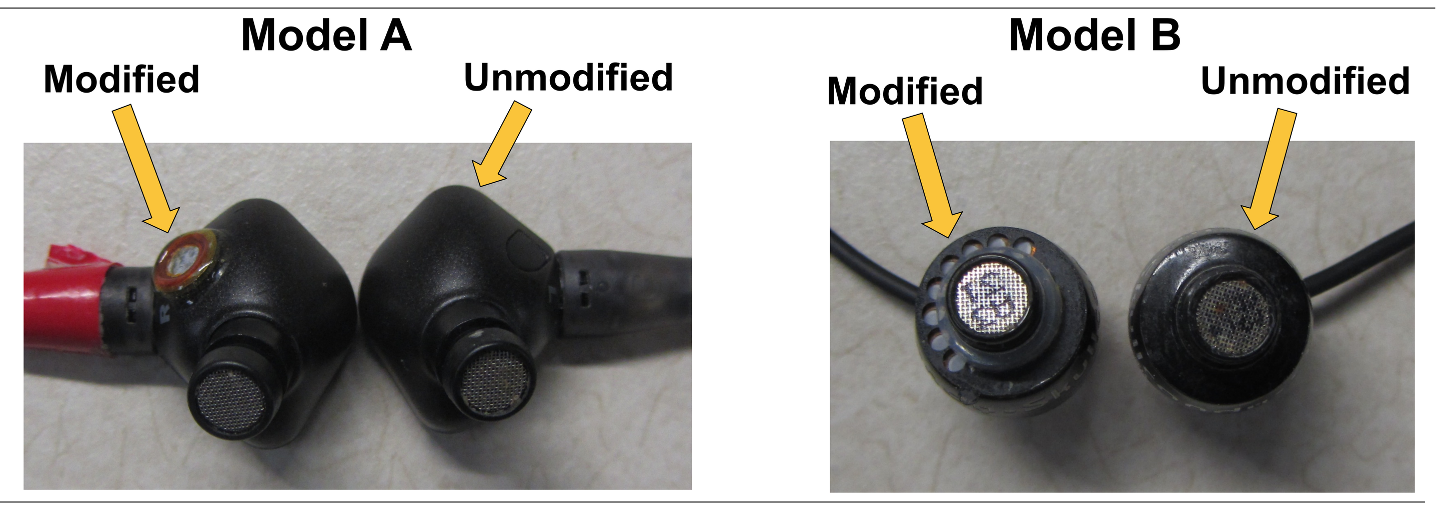
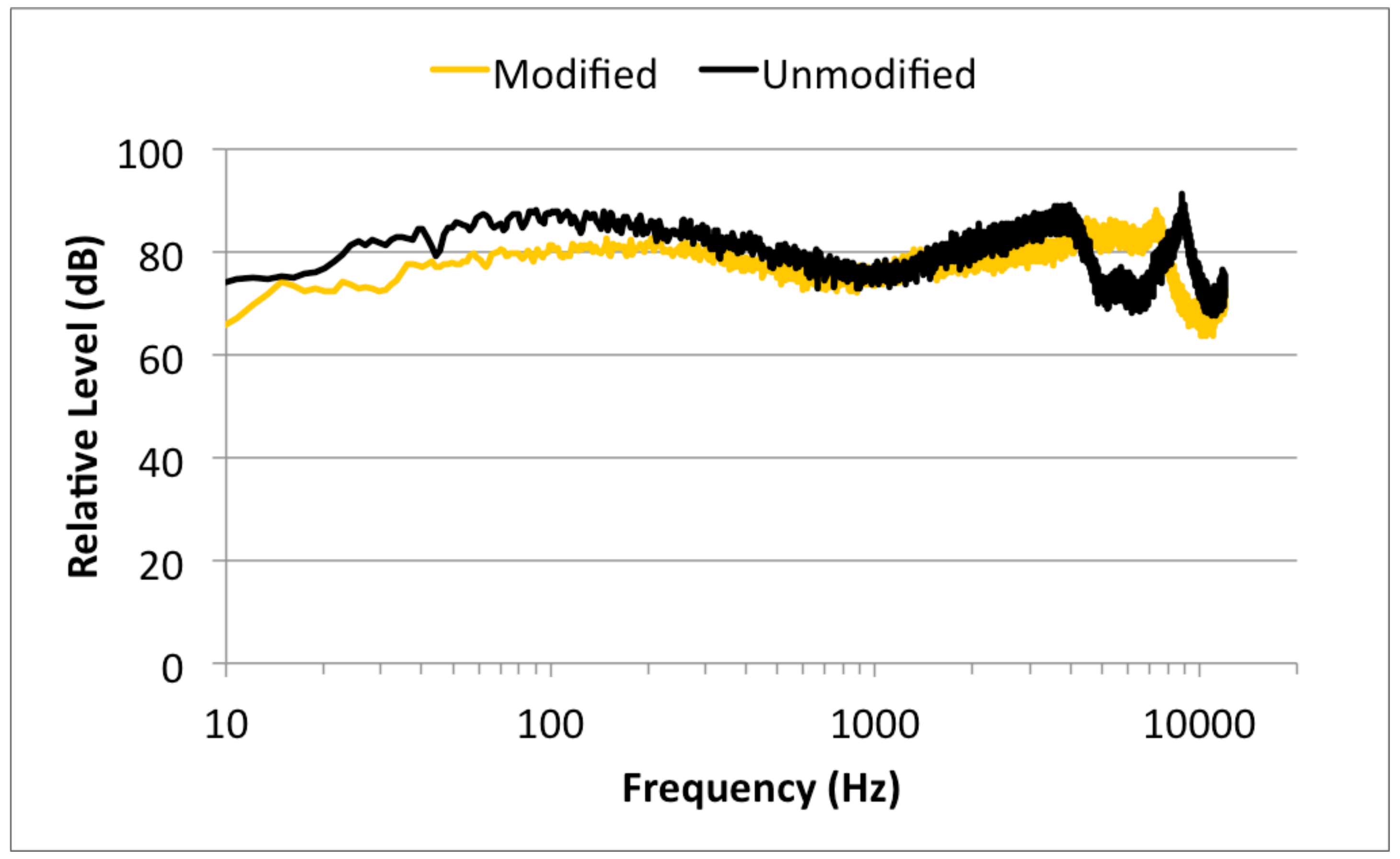


Figure 1. *The modified and unmodified versions of both earphone models. Note: The modification for Model A consisted of a single relatively large membrane, whereas the modification for Model B consisted of multiple smaller membrane covered vents.*

Frequency Response for the Modified and Unmodified Earphones



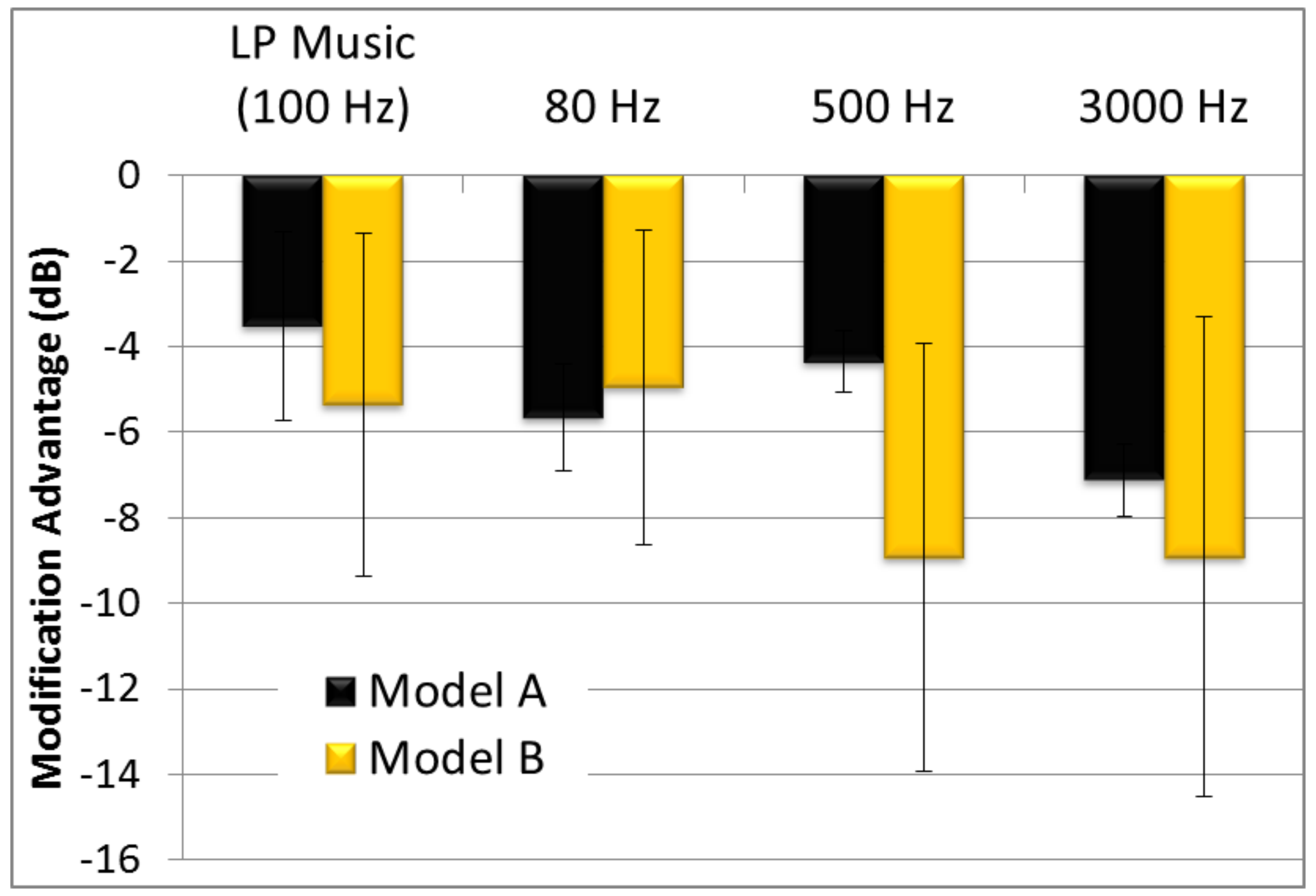
As expected, the modification did effect the earphone frequency response as demonstrated in Figure 2. However, it is also evident that there was considerably less low frequency loss than would be expected for a large vent. While only data for Model B are presented in this figure, a similar small reduction in low frequency output was evident in Model A.

Figure 2. *The frequency response of the modified and unmodified versions of the same commercial insert earphone (Model B).*

Perceived Loudness for the Modified and Unmodified Earphones

The relative level required for the modified versus unmodified earphones to produce the same perceived loudness across frequency is shown in Figure 3. A repeated-measures ANOVA with three within-subject variables (Earphone Model, Modification Status, Signal) revealed significant main effects of Modification Status ($F_{1,17}$ = 28.82, p < 0.001, partial η2 = 0.692) and a significant effect of Signal ($F_{3,17}$ = 77.59, p < 0.001, partial η2 = 0.885). No other significant main effects or interactions were present. These results demonstrate that the level for the modified earphone was significantly lower than the unmodified earphone regardless of brand or signal. On average, the magnitude of advantage observed with the modified earphone ranged from approximately 3.5 dB to 9 dB.

Figure 3. *The magnitude of level advantage for the modified versions of both earphone models for each of the four stimuli which resulted in the same perceived loudness.*



DISCUSSION

- The frequency responses of the unmodified earphones and the modified versions of those same earphones were similar, providing evidence that the method of modification used resulted in only a small loss of low frequency output.
- The magnitude of level advantage demonstrated here for the modified earphones is similar, albeit slightly smaller than the 10 dB previously reported for open ear conditions (Keidser et al, 2000).
- In contrast to these previous data, the level advantage in the current study was present across all frequencies tested rather than being limited to only low frequency sounds (Keidser et al, 2000).
- We speculate that the level advantage may be due in part to the change in natural impedance of the tympanic membrane (TM) in the closed configuration. Previous work has demonstrated that the specific TM impedance can significantly effect sound threshold (Rosowski et al, 1995). It therefore follows that differences in TM impedance may also affect loudness perception.

Conclusion: A significant level advantage was observed for narrowband stimuli (pure tones and low-passed music) using a modified version of two commercially-available insert earphone models. That is, when compared to the unmodified earphones, individuals listening to sound through earphones modified in this way were able to do so at lower absolute levels for the same perceived loudness. Importantly, the level advantage was observed for both low and high frequency stimuli, a result which is in partial contrast to previous findings demonstrating an advantage of the open ear condition, albeit only for the low frequencies. Findings presented here are promising; however, additional work is needed in order to determine whether the level advantage is also present for broadband stimuli.

REFERENCES

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