

# Audiometric Configurations in Children

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## Introduction

Recent studies suggest that the amplification needs of children and adults differ due to differences in perceptual ability. For example, several studies have confirmed that children realize greater benefit from a more audible speech signal (Stelmachowicz, Hoover, Lewis, Kortekaas and Pittman 2000; Stelmachowicz, Pittman, Hoover, Lewis and Moeller 2004), a higher signal-to-noise ratio (Hall and Grose 1991; Veloso, Hall and Grose 1990), and an extended frequency response (Kortekaas and Stelmachowicz 2000; Stelmachowicz, Pittman, Hoover and Lewis 2001) compared to adults. In addition to these aspects, a comparison of the audiometric configurations of these two groups also may be appropriate. The hearing losses of children have been observed in clinical practice to be unlike those of adults in that they are not typically sloping in configuration. Because pure-tone thresholds are used to prescribe amplification characteristics (e.g., gain, output, compression), it seemed reasonable to compare the audiometric configurations of children and adults to determine whether or not differences that are fundamental to amplification exist. For that reason, Pittman and Stelmachowicz (2003) compared the audiometric configurations, bilateral symmetry, and progression of hearing loss over time in children and adults with hearing loss. The purpose of this chapter is to describe the results of that study as well as several additional analyses that highlight interesting aspects of amplification in children.

## Methods

Audiograms were obtained from a database held at Boystown National Research Hospital. Because the database at that time contained approximately 30,000 audiograms, relatively strict criteria were imposed with the knowledge that an adequate number of audiograms would meet those criteria and that the quality of the data obtained would be high. Specifically, thresholds for the right ear only were obtained for 6-year-old children and 60- to 61-year-old adults. (Because the patient population at Boystown National Research Hospital is heavily pediatric, an equal number of adult audiograms could not be obtained without increasing the age range to include 61-year-olds.) The audiograms were required to have right-ear thresholds for each octave test frequency between 250 and 8000 Hz with at least one threshold  $\geq 30$  dB HL (to exclude the audiograms of normal-hearing patients). Finally, losses were confirmed to be sensorineural through bone conduction audiometry, with air-bone gaps that did not exceed 10 dB. For audiograms having thresholds for both supra-aural (TDH-series) and insert (ER-3A) earphones obtained on the same day, the better of the two thresholds at each frequency was used. In clinical practice, however, this is not recommended, particularly for thresholds obtained from small children. See Appendix A for a more detailed discussion of this issue.

The ages of the children and adults (six and 60-year-olds) were selected to represent the etiologies typical of each group. For example, 6-year-old children were selected to represent children with likely congenital or early acquired hearing losses that were present during speech and language development. Although younger children were considered, more audiograms were available for 6-year-olds as they are

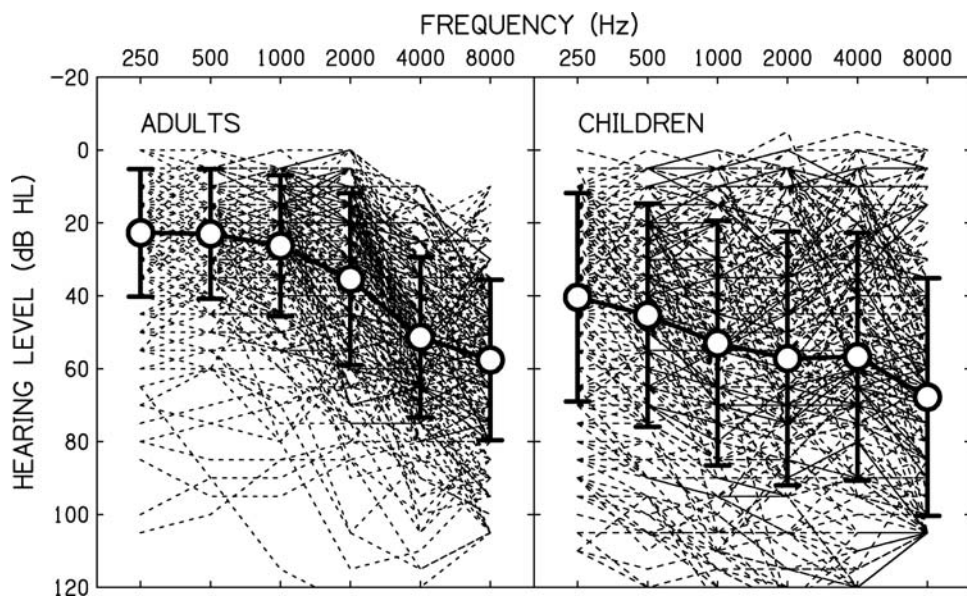
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better able to complete an entire evaluation in one visit. The 60- to 61-year-olds represented older adults who were more likely to have etiologies consistent with acquired losses such as presbycusis, trauma, and/or disease. It is important to note that children actually comprise a small portion of individuals with hearing loss. According to statistics provided by the National Institutes of Health, approximately 28 million Americans have hearing loss. Only about 18% or 1.7 million of those are children. In order to compare the two groups in this study, equal numbers of audiograms had to be obtained by over-sampling the database for audiograms of children. It is likely that a small percentage of the adults in this sample had their hearing losses from early childhood but through statistical averaging the characteristics of the remaining adults reduced any affect of those losses on the overall results.

The results of the query produced 227 audiograms for the children and 248 audiograms for the adults. Those audiograms comprised the core dataset for which three separate analyses were performed: 1) a comparison of the audiometric configurations across groups, 2) a comparison of the symmetry of hearing loss between ears, and 3) an estimate of progression of loss over time. The second and third analyses required that additional data be obtained from the original audiogram or from the database, respectively, but only for the patients represented in the core dataset.

For the first analysis, the configurations of the audiograms were classified into one of five categories: SLOPING, RISING, FLAT, U-SHAPED, and TENT-SHAPED. Those audiograms that did not meet the criteria for inclusion into one of these categories were classified as OTHER. For the specific parameters associated with each category the reader is referred to Pittman and Stelmachowicz (2003). To determine the symmetry of hearing loss in the second analysis, the left-ear thresholds for each patient were obtained from the original audiograms and compared with those of the right ear at each test frequency. The same criteria for inclusion were applied to the left-ear thresholds as in the initial search except that the thresholds did not have to indicate a sensorineural hearing loss or any hearing loss at all. For the third analysis in which the progression of loss was examined, the most recent audiogram for each patient in the core dataset was obtained from the audiogram database. Progression of loss was calculated as the difference between the original audiogram and the most recent or subsequent audiogram. Because the services offered at Boystown National Research Hospital are primarily pediatric, an adequate number of subsequent audiograms could not be obtained for the adults. Thus, the analysis was limited to the progression of loss in the children over a period of about nine years. The purpose of this analysis was to characterize progression of loss in general and to determine if progression was



**Figure 1.** Average configuration of loss (solid lines) and individual audiograms (dashed lines) for the adults and children in the left and right panels, respectively. Error bars represent  $\pm 1$  standard deviation.

more or less related to a particular configuration of loss.

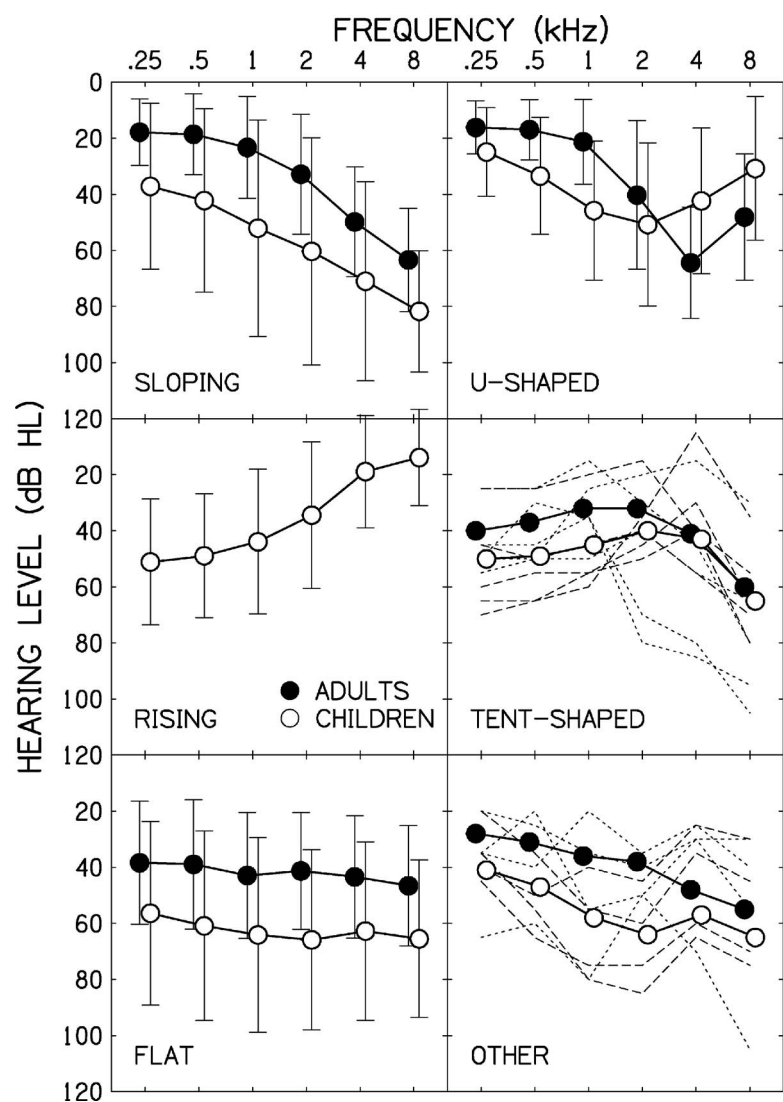
## Results

### Configuration of Loss

Figure 1 shows the average ( $\pm 1$  SD) configuration of loss (solid lines) as well as the individual audiograms (dashed lines) for the adults and the children in the left and right panels, respectively. In general,

the average degree and configuration of loss for each group was similar, although the thresholds for the children were somewhat poorer overall. The individual audiograms that comprised the average configurations suggest substantial differences in the underlying configurations between the groups. Specifically, the adult audiograms appear to cluster around the average whereas the children's audiograms are considerably more variable.

Figure 2 shows the average configurations for each of the six categories of audiograms ( $\pm 1$  SD). The

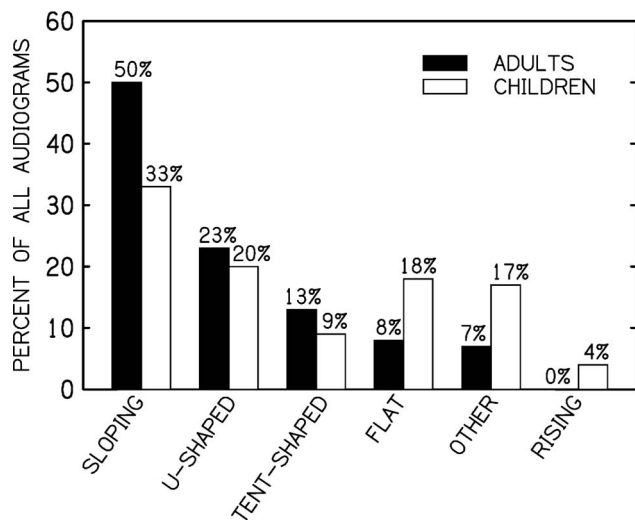


**Figure 2.** Average configurations of loss for the children and adults (open and filled symbols, respectively) for each of six categories. Error bars represent  $\pm 1$  standard deviation. The dashed lines in the TENT-SHAPED and OTHER categories are examples of individual audiograms from adults (long-dashed lines) and children (short-dashed lines).

parameter in each panel is group. Several differences between the groups can be observed from these results. First, the average losses for the children are poorer than the adults in all categories. Second, there were no adults in this dataset with rising configurations of hearing loss. This is consistent with studies of low-frequency hearing loss in which most of the subjects were children or young adults with histories of congenital hearing loss (Florentine and Houtsma 1983; Thornton, Abbas and Abbas 1980; Turner, Burns and Nelson 1983). It is possible that a few of the adults in this dataset had RISING sensorineural hearing losses as children but the effects of aging may have changed those losses to TENT-SHAPED configurations. Third, the standard deviation associated with each configuration suggests that the children's losses varied more in degree of hearing loss than did the adults. This is particularly true for the SLOPING and FLAT configurations. Finally, it is important to note that the unusual shape of the audiograms in the TENT-SHAPED and OTHER categories is obscured by the averaging process. For that reason, several examples of audiograms in each category are also plotted to illustrate the unique nature of these configurations (dashed lines). Although no attempt was made to quantify the severity of the configurations in these categories (e.g., "peakiness" or

“otherness”) it was observed that equally unusual configurations were present in both groups. In other words, the children’s losses were no more unusual than the adult’s losses in these two categories.

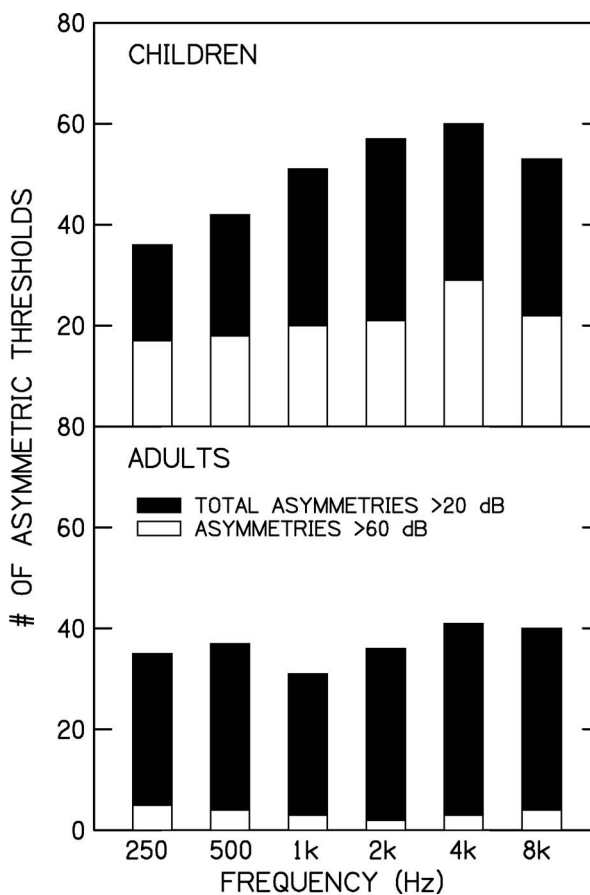
Figure 3 illustrates the percent of audiograms falling into each category for each group. The filled bars represent the adult audiograms and the open bars represent the children’s audiograms. The categories are arranged from most to least frequently occurring configurations in the adults. These results show that 50% of the adult audiograms were SLOPING in configuration with substantially fewer audiograms in all other categories. The children’s audiograms, on the other hand, do not follow the same distribution in that only 33% of the audiograms were SLOPING in configuration. Also, there were as many FLAT and OTHER configurations as there were U-SHAPED losses. Another interesting observation made during data analyses was the similarity between the adult audiograms in the SLOPING and U-SHAPED categories. A comparison of the average configurations in these two categories (the filled symbols in the top two panels of figure 2) suggests that the audiograms differed at 4 and 8 kHz only and by only about 10 dB, on average. The children’s configurations for these two categories were not so similar. These results suggest that almost three-quarters of the adults could be characterized as having SLOPING configurations requiring similar amplification characteristics and that those characteristics may be appropriate for only one-third of the children.



**Figure 3.** Percent of audiogram as a function of configuration category for the adults (solid bars) and the children (open bars).

## Symmetry of Loss

Figure 4 illustrates the extent to which the right-ear thresholds differed from the left-ear thresholds as a function of frequency in the children (upper panel) and adults (lower panel). The stacked bars represent the total number of thresholds that differed by more than 20 dB (filled bars) and those that differed by more than 60 dB (open bars). These data suggest that not only did more children have asymmetric losses but that those losses were more severely asymmetric. Also, the number and severity of the asymmetries in the adults was consistent across frequency whereas more asymmetric losses were observed at 4 kHz in the children followed by 2, 8 and 1 kHz. These differences suggest that, unlike the adults, the hearing losses between ears in the children were likely com-



**Figure 4.** Number of asymmetric thresholds as a function of frequency for the children (upper panel) and the adults (lower panel). The stacked bar configuration represents the total number of asymmetries that were >20 dB (filled bars) relative to the asymmetries that were >60 dB (open bars).

prised of different configurations. Figure 5 shows examples of audiograms from four children with asymmetric losses in this dataset. These examples illustrate the degree of asymmetry between ears as well as the differences in configuration of loss. These configurations are a practical problem for the dispensing audiologist. Because ears and hearing losses are often approached on an individual basis, it is conceivable that very different signal processors could be considered for each ear of one child. Unfortunately, there is little evidence regarding the advantages or disadvantages of such an approach. However, data from children using amplification on the ear opposite of their implanted ear suggest that children can benefit from binaural input of very different characteristics (Ching, Psarros, Hill, Dillon and Incerti 2001).

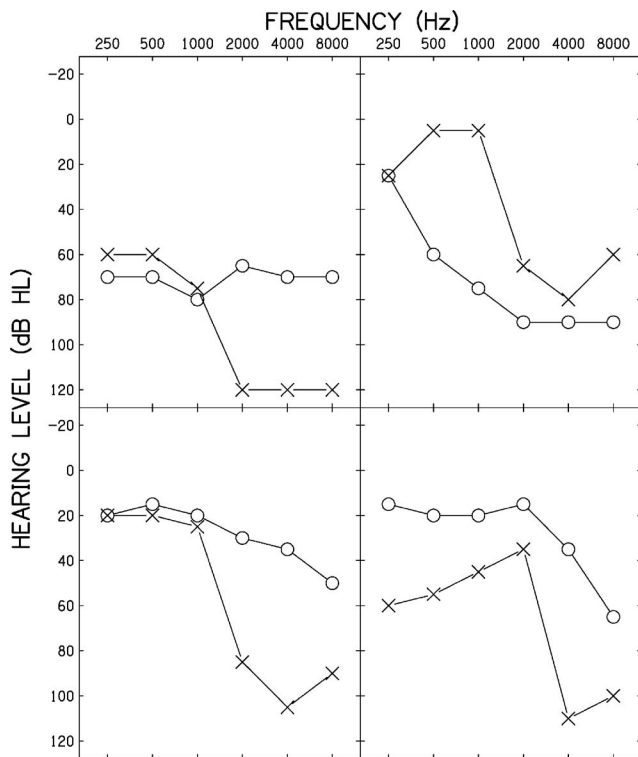


Figure 5. Examples of audiograms from children with asymmetric losses.

### Progression of Loss

Recall that because few subsequent audiograms were available for the adults, progression of loss was determined for the 6-year-old children only. The data

in figure 6 represent the change in threshold at each frequency (from the baseline audiogram to the most recent audiogram) plotted as a function of age at the subsequent (most recent) test.

Positive values reflect progression of hearing loss whereas negative values indicate improvements in

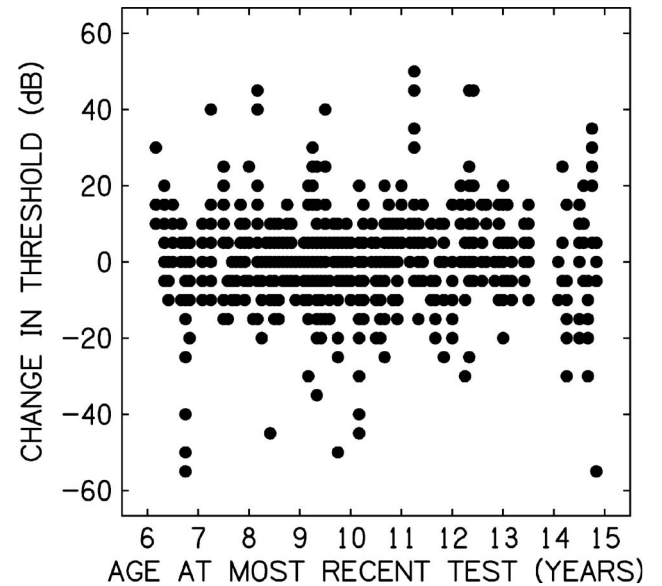


Figure 6. Change in threshold (dB) as a function of age at the most recent audiogram (years) for the children.

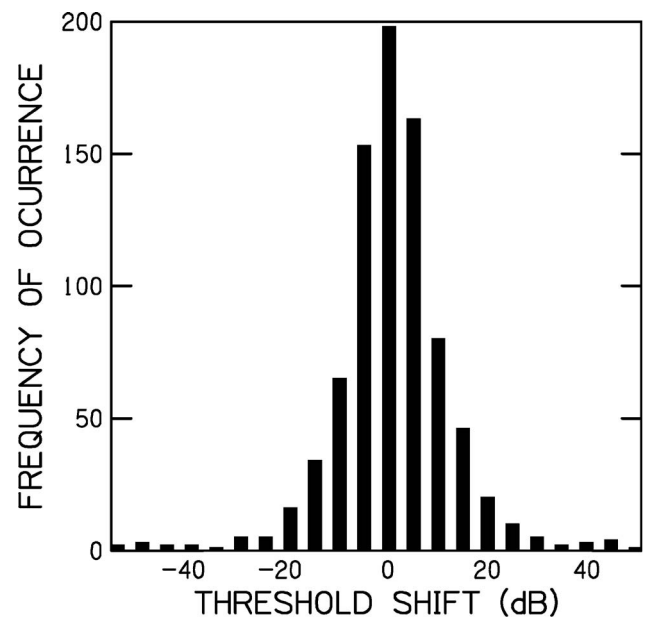


Figure 7. Data in figure 6 replotted to show the number of thresholds as a function threshold shift (dB) for the children.

threshold. These data suggest that most of the thresholds shifted between  $\pm 20$  dB with a few larger positive and negative shifts. Those large shifts appeared to be independent of age at the most recent test. To determine the most commonly occurring values of threshold shift, these data were replotted in figure 7 as the number of thresholds occurring as a function of threshold shift (in dB). These data show that although the distribution of threshold shifts centered around 0 dB, there was a normal distribution of data on each side of zero indicating nearly equal numbers of improving and deteriorating thresholds. This was unexpected because hearing loss is generally thought to increase over time due to further deterioration of the hearing mechanism. Instead, these data suggest that thresholds were just as likely to improve; a phenomenon that is difficult to explain and rarely discussed in the literature. Further analyses revealed no relation between the degree of threshold shift and test frequency. In other words, there was no indication that the thresholds improved or deteriorated more so at a particular frequency.

## Discussion

This chapter describes a retrospective study of audiometric configurations in children and adults by Pittman and Stelmachowicz (2003). The results suggest that, at the fundamental level of the audiogram, children's hearing losses differ substantially in configuration from those of adults. Based on the 475 audiograms evaluated, 74% of the adult's audiograms and 33% of the children's audiograms were SLOPING in configuration. The remaining 26% of the adult audiograms were distributed across three configurations (TENT-SHAPED, FLAT, and OTHER) whereas the remaining 67% of the children's audiograms were distributed across five configurations (U-SHAPED, TENT-SHAPED, FLAT, RISING, and OTHER). Because much of our knowledge regarding the benefits of new signal processing systems comes from studies in hearing-impaired adults, it is likely that most of those adults had losses that were SLOPING in configuration (assuming a random sample). The results of those studies, then, may not be appropriate for the majority of hearing-impaired children (and a minority of hearing-impaired adults) who have other configurations of loss.

These results also have implications for prescriptive fitting strategies. In general, fitting strategies for children and adults prescribe gain for each hearing

threshold independent of other thresholds. In doing so, the prescribed gain tends to mirror the hearing loss. Even if advanced signal processors could accommodate large excursions in gain from one frequency to the next, it is not clear whether children (or adults) would benefit from such an approach. An inappropriate or inadequate prescription may have long-term consequences for a child who must use his/her hearing to learn speech and language skills. Research into the interaction between hearing loss configuration and the gain prescribed by current fitting strategies may help to optimize speech perception as well as later speech and language development in children with unusual hearing losses.

Finally, it is possible that improvements in hearing thresholds relative to the baseline audiogram may have been due to inattention during testing or inaccurate bone conduction thresholds on the baseline audiogram (suggesting that the original hearing loss was actually conductive rather than sensorineural). However, because those data showed an even distribution around 0 dB, it is unlikely that exactly half of the thresholds obtained at 6 years of age were due to inattention. If so, threshold shifts suggesting deterioration are also suspect. Regardless of the explanation for thresholds shifts, the pediatric audiologist should expect to see thresholds change from one test to the next and consider adjusting the child's amplification when necessary.

## Acknowledgement

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## Appendix A. Relation Between Thresholds Obtained with Supra-Aural and Insert Earphones

At times during an audiometric evaluation, test conditions may warrant the use of more than one transducer (e.g., TDH and ER earphones). For example, the composition of the ear may suggest collapsing ear canals, a small child may not wish to continue with a particular type of transducer, or the presence of middle-ear pathology may produce unexpected test results (Voss et al. 2000; Voss, Rosowski, Shera and Peake 2000). When events lead to the use of two transducers, the two sets of thresholds obtained at each frequency can differ by as much as 10 to 15 dB or more (Clark and Roeser 1988; Frank and Vavrek 1992). Observing such differences on an audiogram may lead the audiologist to wonder which results are accurate. A better question may be to ask why the thresholds differed in the first place. Given the extensive audiometer calibration process and the transforms used to express sound pressure level (SPL) in units of hearing level (HL), it seems reasonable for one to expect similar results from the two transducers. But they rarely are. To understand why,