Bone-Conduction Reference Threshold Levels – a Multicenter Study

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BACKGROUND

Previous studies revealed that bone-conduction thresholds at frequencies above 2000 Hz are numerically lower than air-conduction thresholds, resulting in air-bone gaps in listeners with normal hearing and sensorineural hearing loss (SNHL) (refs 3, 6-8, 10,11). This study was undertaken to establish normal bone-conduction thresholds with methods prescribed by ISO 389-9 which requires that reference threshold levels should be based on thresholds for "otologically normal" subjects. In this study, both normal-hearing and SNHL subjects were tested.

In listeners with SNHL, the false air-bone gap at 4000 Hz increases with the magnitude of the hearing loss (air-conduction threshold) at that frequency (Refs 6,7). It is likely that bone-conduction thresholds of normal-hearing listeners at 4000 Hz and above are artificially elevated by the internal noise of the auditory system. As the magnitude of the hearing loss increases, the test signals are increasingly higher than the noise floor providing an accurate measurement of bone-conduction sensitivity. In this study the relationship between bone-conduction sensitivity and the magnitude of the hearing loss at the test frequency was examined and recommendations for revisions of reference equivalent threshold force levels were derived. The recommendations are based on the principal that average air-bone gaps for listeners with SNHL should be 0 dB.

METHODS

ISO 389-9:2009 provides recommended procedures for the determination of hearing threshold levels that are used to define Reference Equivalent Threshold Sound Pressure Levels and Reference Equivalent Threshold Force Levels (provided in the audiometer standards ANSI S3.6, ISO 389-1 and ISO 389-3, Refs 1,4). Audiometers used in this study were calibrated with the same calibration equipment in accordance with ISO 389-9.

Data were collected at three sites – Arizona State University (ASU), Cincinnati Children's Hospital Medical Center (CCHMC), and University of South Florida (USF). Automated and manual audiometric methods were employed. Bone vibrator placement was forehead (USF, CCHMC) and mastoid (ASU).

A total of 59 normal-hearing listeners and 49 listeners with SNHL were tested. Air-conduction thresholds were tested in one ear (equal numbers of right and left ears) with a circumaural earphone (Radioear DD450) at standard octave and interoctave frequencies (250 – 8000 Hz). Bone-conduction thresholds were tested in one ear with a Radioear B-81 bone vibrator at the same frequencies. Bone-conduction testing with forehead placement was performed with the bone vibrator secured by an elastic headband (Ref 9), the test ear uncovered and the non-test ear covered with the circumaural earphone to deliver masking. Bone-conduction testing with mastoid placement was performed with the test ear uncovered and the non-test ear covered with the masking earphone. All testing was performed in sound-attenuating rooms.

RESULTS

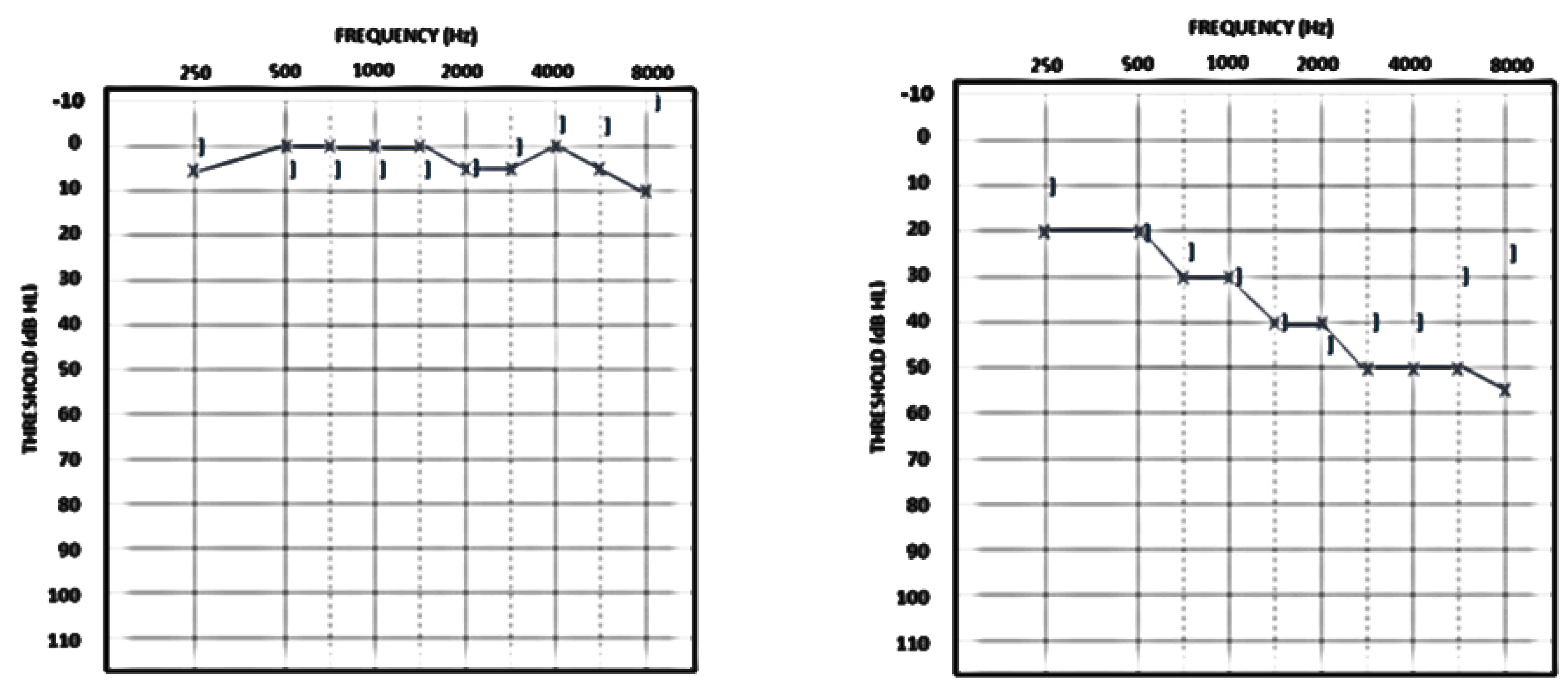

Figure 1. Average air and bone-conduction thresholds (rounded to the nearest 5 dB) for the test ear of normal-hearing listeners (left panel) and listeners with sensorineural hearing loss (right panel).

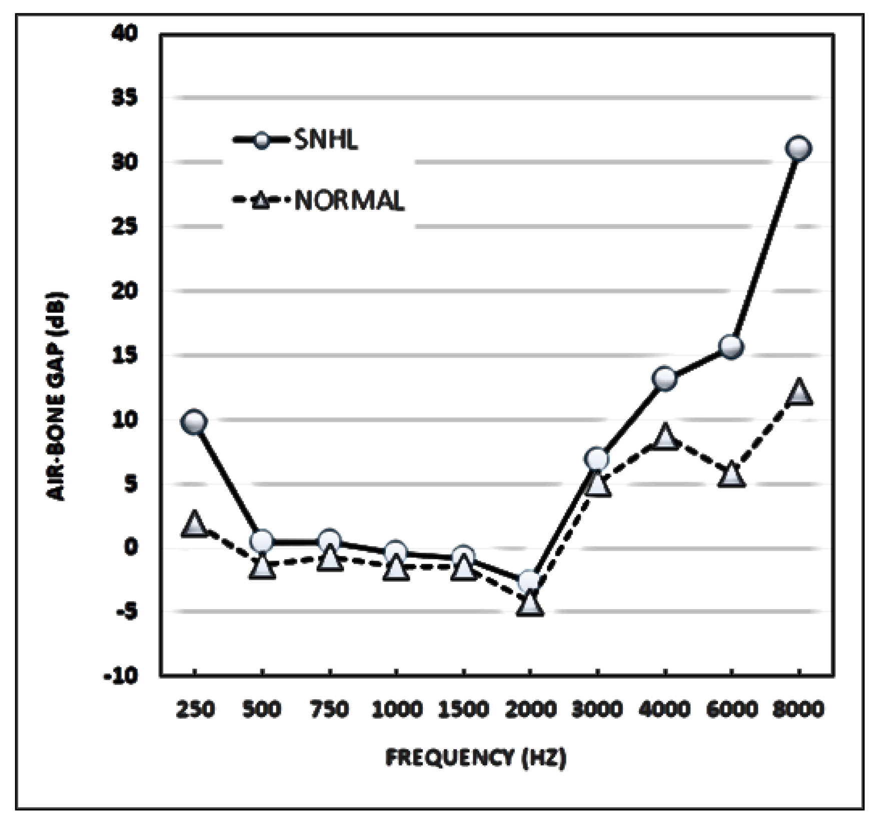

Figure 2. Mean air-bone gaps for normal-hearing listeners and listeners with SNHL plotted against signal frequency. The difference in air-bone gaps in the high frequencies results from the effect of noise floor on bone thresholds for the normal-hearing group.

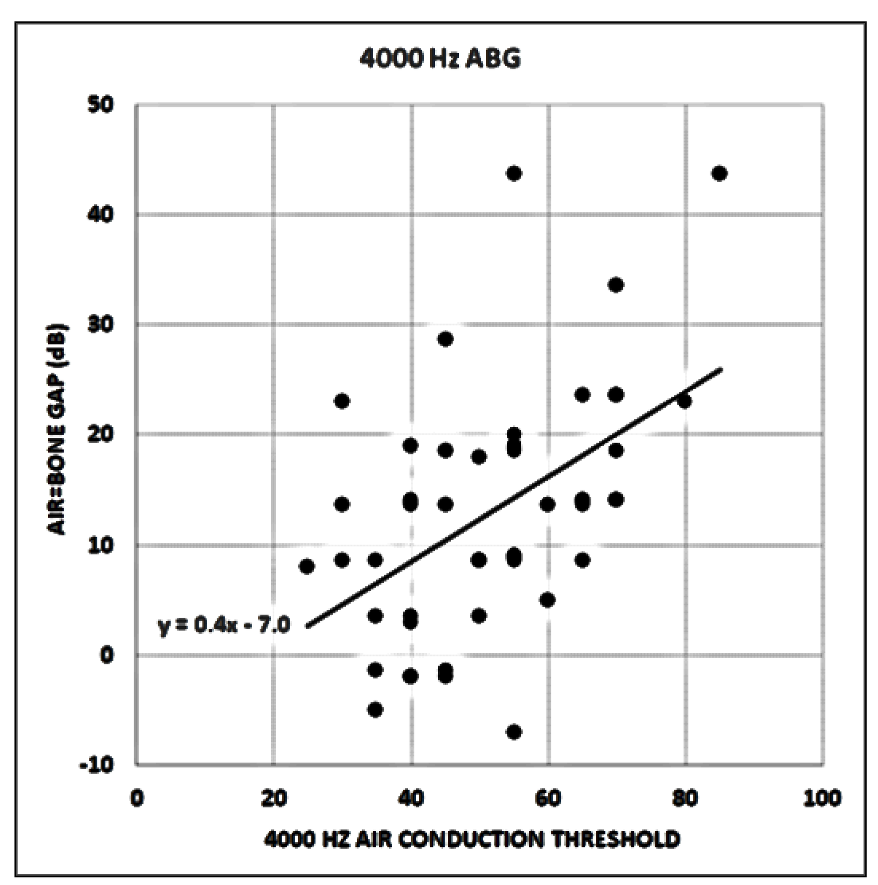

Figure 3. 4000 Hz air-bone gaps for 49 listeners with SNHL plotted against the 4000-Hz air-conduction threshold. The solid line is the best fit linear function. The air-bone gap grows at a rate of 0.4 dB/dB as the 4000-Hz air-conduction threshold increases.

DISCUSSION

Average bone-conduction thresholds are numerically lower than air-conduction thresholds for test frequencies above 2000 Hz. These air-bone gaps result from erroneous reference equivalent threshold force levels in the audiometer standards (Refs. 1,4). The false air-bone gaps are greater for listeners with SNHL than for normal-hearing listeners. In listeners with SNHL, the false air-bone gaps at high frequencies increase with the magnitude of the hearing loss at the test frequency (Figure 3).

Expressed in force levels (dB re 1 µN) bone-conduction thresholds decrease with increasing frequency at a rate of -12 dB/oct (Figure 4, Ref. 2, Corliss, 1959). This steep decrease in threshold level approaches the internal noise floor of the auditory system. Around 3000 Hz, internal noise begins to elevate bone-conduction thresholds in normal-hearing listeners.

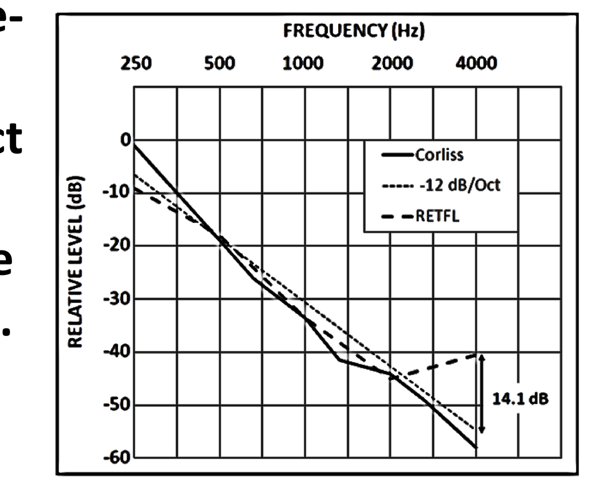

Figure 4

The elevated thresholds of listeners with SNHL should be taken into account in specifying reference-equivalent threshold force levels. The higher thresholds decrease the contaminating influence of the noise floor that artificially elevates bone-conduction thresholds in normal-hearing listeners, especially at high frequencies. The requirement in ISO 389-9 that only threshold levels of listeners with normal hearing are considered in determining reference levels has led to the occurrence of air-bone gaps in listeners with SNHL. These false air-bone gaps can be misinterpreted as evidence of middle-ear involvement in patients with inner-ear pathology and can result in unnecessary testing, unnecessary referral, and even unnecessary treatment like medication and surgery. Based on the data from this study and corroborating evidence from other studies we recommend the following reference-equivalent threshold force levels for the calibration of bone-conduction stimulis presented by audiometers.

Table 1. Recommended Reference Equivalent Threshold Force Levels (dB re 1 µN).

	250 Hz	500 Hz	750 Hz	1000 Hz	1500 Hz	2000 Hz	3000 Hz	4000 Hz	6000 Hz	8000 Hz
Mastoid	57.3	57.6	48.0	43.0	37.3	33.7	23.2	22.5	24.4	9.0
Forehead	69.3	71.6	61.0	51.5	48.3	45.2	35.2	30.5	35.4	19.0

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