AIR-BONE GAPS AT 4 kHz IN SENSORINEURAL HEARING LOSS

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INTRODUCTION

The first standard bone-conduction threshold norms appeared in the 1972 American audiometer standard (ANSI S3.13-1972). Soon after these reference equivalent threshold force levels (RETFLs) were adopted, clinicians began to commonly see air-bone gaps at 4 kHz in subjects with normal middle-ear function. In subsequent American and international standards, the RETFLs were modified slightly and values were added for additional frequencies, but the values in the 1972 standard remain very close to those in the current standards (ANSI S3.6 – 2010; ISO 389.3 – 1994).

The objective of this study was to assemble available data from published and unpublished studies to examine the standard bone-conduction RETFL, especially at 4 kHz where inappropriate air-bone gaps from subjects with SNHL are common.

BACKGROUND

It has been hypothesized that acoustic radiation from the bone vibrator at 4 kHz could be contaminating these bone-conduction threshold measurements. This was disproven by Frank and Holmes (1981) when no difference was found between 4-kHz bone-conduction thresholds with the test ear plugged and unplugged, indicating that acoustic radiation did not affect the bone-conduction threshold.

The 4-kHz air-bone gaps reported by Margolis et al (2010) also provide strong evidence that the large air-bone gaps for subjects without conductive hearing loss cannot be attributed to acoustic radiation. They reported air-bone gaps from sensorineural hearing loss (SNHL) subjects that averaged 19.3 dB for an automated pure-tone audiometry method (AMTAS) and 13.2 dB for manual audiometry. In a follow-up study (Margolis & Moore, 2011), 4-kHz air-bone gaps for SNHL subjects averaged 10.8 dB for AMTAS and 13.4 dB for manual audiometry. AMTAS bone conduction thresholds were obtained with forehead placement of the bone vibrator with both ears covered with circumaural earphones that have about 40 dB of ambient sound attenuation at 4 kHz, eliminating the possibility of audible acoustic radiation.

Lightfoot (1979) suggested that a 4-kHz air-bone gap of about 5 dB could result from acoustic radiation of the Radioear B71 vibrator . However, the studies on which the standard RETFLs are based (e.g. Wilbur & Goodhill, 1967; Dirks et al, 1979), performed bone conduction testing with the test ear unoccluded, so any effect of acoustic radiation would be incorporated into the RETFLs.

METHODS

Studies were selected that measured air- and bone-conduction thresholds for subjects with normal hearing and with SNHL using manual audiometry and AMTAS. Normal hearing was defined as air-conduction thresholds at 0.5, 1.0, 2.0, 4.0 kHz less than or equal to 20 dB HL. SNHL was defined as four-frequency, air-conduction, pure-tone averages greater than 20 dB with air-bone gaps at 0.5, 1.0, and 2.0 kHz less than or equal to 5 dB. A brief description of each study follows.

Study 1 (Margolis et al., 2010)

Subjects with SNHL were recruited and tested by the University of Cambridge Psychoacoustics Laboratory. Each subject was tested by manual audiometry with mastoid bone conduction placement by an experienced audiologist and by AMTAS with forehead bone conduction. Sennheiser HDA 200 circumaural earphones were used.

Study 2 (Margolis & Moore, 2011)

Normal and SNHL subjects were recruited and tested by the Audiology Research Laboratory of the University of Minnesota Hospital. Each subject was tested by manual audiometry by an experienced audiologist using Telephonics TDH-50 earphones and mastoid bone conduction placement and by AMTAS using Sennheiser HDA 200 earphones and forehead bone conduction placement.

Study 3 (Margolis, Johnson, & Stiepan, unpublished)

Normal and SNHL subjects were recruited and tested by the Audiology Research Laboratory of the University of Minnesota Hospital. Each subject was tested by manual audiometry by an experienced audiologist using Telephonics TDH-50 earphones and mastoid bone conduction placement and by AMTAS using Sennheiser HDA 200 earphones and forehead bone conduction placement. To avoid bias during manual bone-conduction testing, offsets ranging from -10 to 10 dB were introduced into the bone-conduction calibration constants stored by the audiometer and later removed before final analysis.

Study 4 (Eikelboom & Swanepoel, unpublished)

Subjects were from the Busselton Healthy Ageing Study (BHAS), a detailed survey of the health of up to 4000 residents (born between 1946 and1964) in the Shire of Busselton, Western Australia. Enrollment into the study was randomized with 10% of the available sample drawn and recruited at a time. Data used in this analysis were from the first 1004 participants age 45 to 65 years at time of examination. Each subject was tested by AMTAS using Sennheiser HDA 200 earphones and forehead bone conduction placement.

Study 5 (Mehta & Bauch, 2005)

Normal-hearing subjects were recruited and tested by the Mayo Clinic, Rochester, Minnesota. Manual audiometry was performed using TDH-50 earphones by an experienced audiologist with both forehead and mastoid placement of the bone vibrator.

Study 6 (Stephany et al., 2007)

Normal-hearing subjects were recruited and tested by the Mayo Clinic, Rochester, Minnesota. Manual audiometry was performed using Telephonics TDH -50 earphones by an experienced audiologist.

RESULTS

Mean air-bone gaps, sample sizes, and weighted means for normal-hearing subjects are shown in Table 1. Small air-bone gaps were evident at 0.5, 1.0, and 2.0 kHz (weighted means between -2.6 and 0 dB). At 4.0 kHz the weighted mean air-bone gap is 8.5 dB.

Mean air-bone gaps, sample sizes, and weighted means for SNHL subjects are shown in Table 2. There was a substantially larger air-bone gap at 4 kHz for the SNHL subjects with a weighted mean of 14.1 dB and small air-bone gaps at 0.5, 1.0, and 2.0 kHz (-0.7 to 1.7 dB).

The relationship between the air-bone gap and the magnitude of the hearing loss is shown in Figures 1 and 2. At 1-kHz (Figure 1) the air-bone gap did not change with the magnitude of the hearing loss. At 4 kHz (Figure 2) the air-bone gap increased monotonically with increasing 4-kHz air-conduction threshold, from 10.1 dB for subjects with thresholds of 5 or 10 dB HL to 22.1 dB for subjects with thresholds > 60 dB HL.

Figure 3 shows the current standard RETFLs and an adjusted RETFL at 4 kHz. The shaded diamond shows the standard 4-kHz RETFL corrected by the weighted mean 4-kHz air-bone gap for SNHL subjects. The standard RETFLs and the corrected 4-kHz value are described well by a regression line that has a slope of about –12 dB per octave.

To explore the possibility that the 4 kHz air-bone gap could be due to an age-related change in middle-ear transmission we examined the relationship between the 4-kHz air-bone gap and age. A split-half analysis based on age indicated no significant effect of age on the 4-kHz air-bone gap (Figure 4A). To explore the possibility that an age effect is evident only for subjects with greater hearing losses, we narrowed the groups to those with 4-kHz air-conduction thresholds > 35 dB. Again no significant age effect was evident (Figure 4B). These analyses do not support the hypothesis that there is an age-related conductive component at 4 kHz, although it is possible that an effect would have emerged if the groups had spanned a wider age range.

Table 1. Mean air-bone gaps (air-conduction threshold minus bone-conduction threshold) for normal-hearing subjects.

				Frequency (kHz)			
	Method	BC Location		0.5	1.0	2.0	4.0
Study 3	Manual	Mastoid	Mean	0.0	3.4	-1.3	5.6
			n	16	16	16	16
	Manual	Forehead	Mean	-1.8	6.1	-4.6	6.8
			n	14	14	14	14
Study 4	AMTAS	Forehead	Mean	0.4	-0.3	-1.5	11.1
			n	235	235	235	235
Study 5	Manual	Mastoid	Mean	-9.3	-2.0	-9.0	-1.5
			n	20	20	20	20
	Manual	Forehead	Mean	-4.0	-5.8	-3.3	0.0
			n	20	20	20	20
Study 6	Manual	Mastoid	Mean	-1.2	2.8	-6.0	2.7
			n	30	30	30	30
		All	Weighted Mean	-0.7	0.0	-2.6	8.5
			n	335	335	335	335
		Mastoid	Weighted Mean	-3.4	1.5	-5.8	2.1
			n	66	66	66	66
		Forehead	Weighted Mean	0.0	-0.4	-1.8	10.1
			n	269	269	269	269

Table 2. Mean air-bone gaps (air-conduction threshold minus bone-conduction threshold) for subjects with sensorineural hearing loss.

				Frequency (kHz)			
	Method	BC Location		0.5	1.0	2.0	4.0
Study 1	Manual	Mastoid	Mean	1.3	1.0	-0.5	12.5
			n	20	20	20	20
	AMTAS	Forehead	Mean	4.6	1.7	2.5	20.0
			n	15	15	16	19
Study 2	AMTAS	Forehead	Mean	-8.4	2.8	-6.6	10.8
			n	17	18	19	20
	Manual	Mastoid	Mean	-5.0	-2.2	-6.8	13.4
			n	16	19	20	20
Study 3	AMTAS	Forehead	Mean	6.5	5.2	9.3	17.4
			n	23	24	20	16
	Manual	Mastoid	Mean	5.3	3.9	1.4	12.2
			n	27	29	25	16
Study 4	AMTAS	Forehead	Mean	0.8	0.6	-1.9	13.7
			n	63	63	63	61
		All	Weighted Mean	1.2	1.7	-0.7	14.1
			n	181	188	183	172
		Mastoid	Weighted Mean	1.4	1.3	-1.7	12.7
			n	63	68	65	56
		Forehead	Weighted Mean	1.1	2.0	-0.2	14.7
			n	118	120	118	116

Figure 1. Average 1-kHz air-bone gaps for subject groups stratified by the 1-kHz air-conduction threshold. Data labels show average air-bone gap and sample size. Vertical lines show 95% confidence intervals.

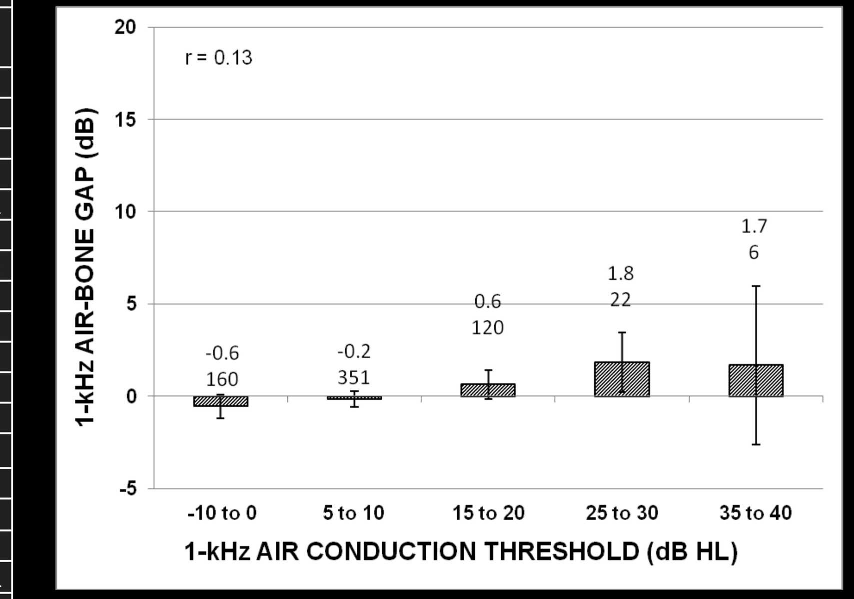


Figure 2. Average 4-kHz air-bone gaps for subject groups stratified by the 4-kHz air-conduction threshold. Data labels show average air-bone gap and sample size. Vertical lines show 95% confidence intervals.

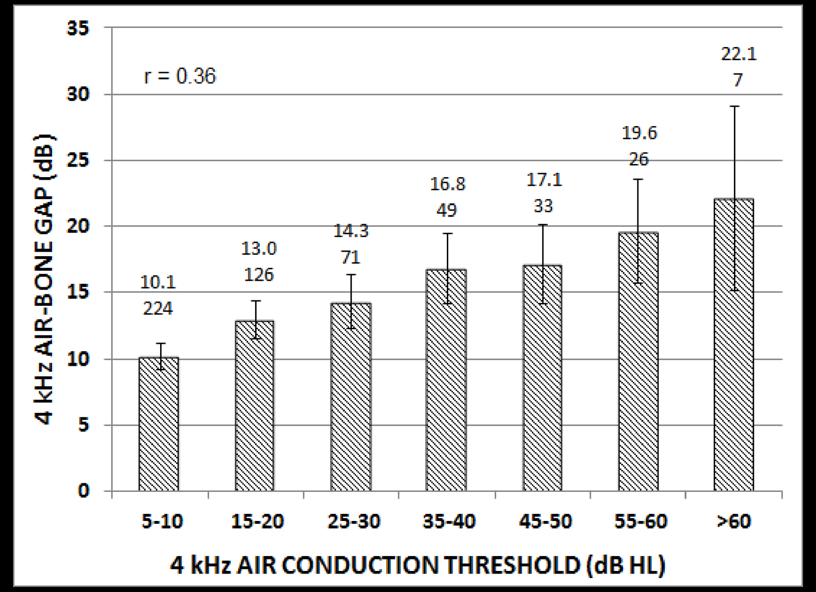


Figure 3. Reference Equivalent Threshold Force Levels from ANSI S3.6 – 2010 and ISO 389.3 – 1994 (black diamonds). The gray diamond shows the standard RETFL corrected by –14.1 dB. The solid line is the best-fit linear regression line fit to the data from 0.25 to 2.0 kHz and extrapolated to 4.0 kHz.

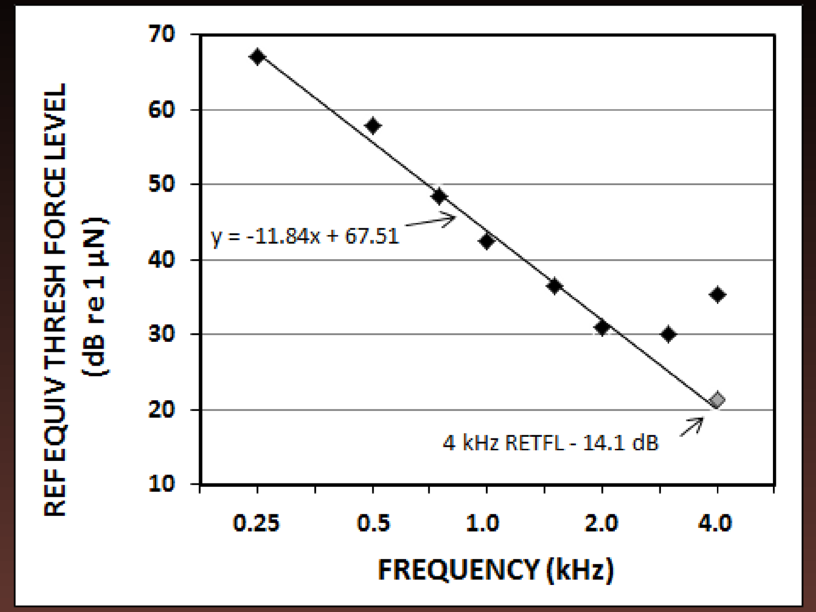
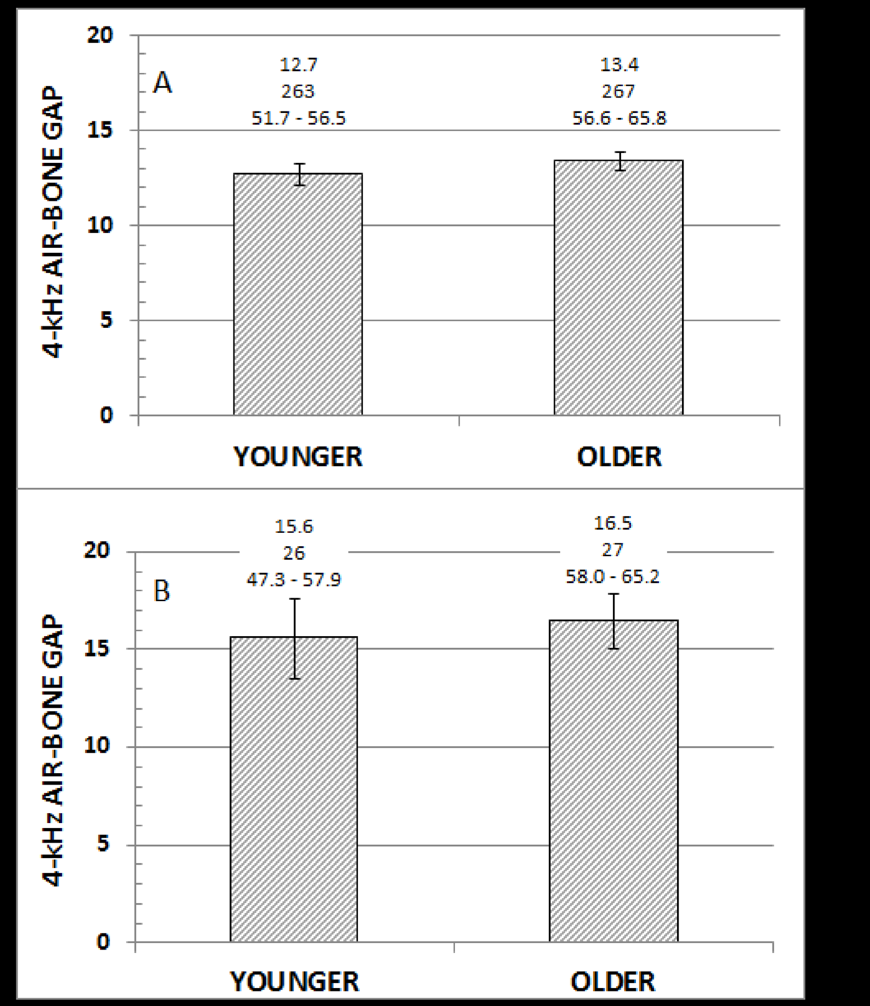


Figure 4. 4-kHz air-bone gaps from younger and older groups of subjects. **A.** Subjects with air-bone gaps at 0.5, 1.0, and 2.0 kHz ≤ 5 dB and 4-kHz air conduction thresholds greater than 0 dB HL. **B.** Subjects with air-bone gaps at 0.5, 1.0, and 2.0 kHz ≤ 5 dB and 4-kHz air conduction thresholds greater than 35 dB HL. Data labels show mean air-bone gaps, sample sizes, and age ranges (yrs). Error bars show ±1 standard error of the mean.



CONCLUSIONS

- Normal-hearing subjects had small air-bone gaps at 0.5, 1.0, and 2.0 kHz (weighted means from -2.6 to 0 dB) and a larger air-bone gap at 4 kHz (weighted mean 7.1 dB).
- SNHL subjects had small air-bone gaps at 0.5, 1.0, and 2.0 kHz (weighted means from -0.7 to 1.7 dB) and a larger air-bone gap at 4 kHz (14.1 dB). This suggests an inappropriate RETFL exists at 4 kHz and an adjustment of –14.1 dB would reduce these air-bone gaps to an average of 0 dB for subjects with 4-kHz air-conduction thresholds > 20 dB HL.
- For groups stratified by the air-conduction threshold, the 4-kHz air-bone gap grows monotonically in magnitude from 10.1 dB when the pure-tone threshold is 5 - 10 dB HL to 20.1 dB when the pure-tone threshold is greater than 60 dB HL.
- Greater hearing loss at 4 kHz is associated with a greater air-bone gap. There is no significant effect of age on the 4-kHz air-bone gap.
- If the standard 4-kHz RETFL is corrected by the average air-bone gap for subjects with SNHL (14.1 dB), the relationship between RETFL and frequency is a linear function (on logarithmic coordinates) with a slope of –12 dB per octave. A set of RETFLs that conform to that slope may be appropriate and helpful for defining RETFLs at other frequencies where there are less definitive data (such as 3 and 6 kHz).
- A correction of –14.1 dB may slightly elevate bone-conduction thresholds for subjects with normal hearing. This is not a significant concern because a) it is common to omit bone-conduction testing when the air-conduction threshold is normal; and b) a slight elevation in bone-conduction threshold for a normal-hearing subject will not result in a diagnostic error.

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