Acoustic method for calibration of audiometric bone vibrators. II. Harmonic distortion

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Abstract: A previous report [Margolis and Stiepan (2012). "Acoustic method for calibration of audiometric bone vibrators," J. Acoust. Soc. Am. **131**, 1221–1225] described a reliable, inexpensive, acoustic method for calibration of audiometric bone vibrators. As a follow up to that report harmonic distortion measurements were made with the standard electromechanical method and the acoustic method using five Radioear B71 vibrators and one Radioear B81 prototype vibrator. Lower distortion was seen for measurements made with the acoustic method compared to the electromechanical method and for the Radioear B81 vibrator compared to the Radioear B71 vibrator.

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1. Introduction

Bone-conduction calibration allows for accurate measurement of inner-ear hearing sensitivity. Since bone vibrators are placed on the mastoid or forehead in order to deliver a vibratory signal to the inner ear, calibration devices that have measured the output of the bone vibrator have tried to mimic the mechanical-impedance properties of the average adult human head. This standard electromechanical method for audiometric bone vibrator calibration has utilized predominantly the Bruel & Kjaer type 4930 artificial mastoid. The artificial mastoid converts the mechanical signal produced by the bone vibrator to an electrical analog signal which is measured by a device such as a volt meter, oscilloscope, or sound level meter. The B&K type 4930 artificial mastoid is the only commercially available device that conforms to standards related to bone-conduction calibration (ANSI, 1972, 1996; IEC, 2007).

In a previous report, Margolis and Stiepan (2012) argued that the calibration device does not need to mimic the mechanical properties of the human head, but it must provide a stable and reproducible output that can be correlated to the normal threshold of audibility for bone-conducted stimuli. An acoustic coupler was designed to couple the Radioear B71 10-ohm and 50-ohm bone vibrators to an acoustic earphone coupler (IEC, 2009). The acoustic coupler captures the acoustic radiation emitted from the bone vibrator and delivers it to a microphone where the signal is converted into an electrical analog with an amplitude that is proportional to the force produced by the vibrator. Measurements made with the acoustic method were compared to those made with the electromechanical method for several audiometers and bone vibrators. Measurements made with the acoustic method were characterized by significantly lower variability than those made with the electromechanical method suggesting

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that the acoustic method is an alternative approach to bone-conduction calibration that could decrease cost and increase accuracy.

This report extends the measurements reported by Margolis and Stiepan (2012) to include total harmonic distortion measured with the acoustic and electromechanical methods with five Radioear B71 bone vibrators and a prototype bone vibrator (Radioear B81) designed to extend the output range to allow threshold measurements for subjects with a wider range of hearing losses.

2. Methods

Total harmonic distortion was measured at 250, 500, and 1000 Hz for signals delivered by an audiometer (Madsen Aurical) to five Radioear B71 bone vibrators and one Radioear B81 bone vibrator. For B71 bone vibrators, the signal levels were 20, 50, and 60 dB hearing level (HL) at 250, 500, and 1000 Hz, respectively, as specified by the American audiometer standard (ANSI, 1996). In order to compare measurements made with a defective bone vibrator, one B71 vibrator was altered to intentionally increase the harmonic distortion by loosening the screw that attaches the transducer to its plastic case.

Because the B81 vibrator was designed to produce higher output levels with lower distortion than the B71, a different procedure was followed when measuring harmonic distortion from that device. The B81 is housed in a plastic enclosure that is very similar to the B71. Both devices have circular facets with the same dimensions for contact with the patient. Consequently the acoustic coupler effectively couples the bone vibrators to the earphone coupler and sound level meter. For the B81 bone vibrator, measurements were made with three input levels at each frequency, 0.5, 1.0, and 2.0 Vrms. These levels were chosen because the calibration levels for the device are not in the standards and because we wished to sample their performance for the higher input voltages that they are designed to accept.

For both vibrator types, measurements made with the acoustic method were compared to results obtained with the electromechanical method using a recently calibrated artificial mastoid (Bruel & Kjaer type 4930). The electrical output of the B&K artificial mastoid was delivered to the preamplifier of a sound level meter (Larson Davis System 824). For the acoustic method measurements of the acoustic output of the bone vibrator was measured with a 0.5 in. condenser microphone (Larson Davis model 2559) mounted in a standard audiometric earphone coupler (IEC, 2009) which was coupled to the sound level meter. Because the acoustic coupler is hermetically sealed on the earphone coupler and the bone vibrator forms a hermetic seal on the coupler, the highly reproducible physical arrangement produces repeatable measurements (Margolis and Stiepan, 2012). The sound level meter was calibrated with a commercial signal generator designed for calibration of sound level meters (Bruel & Kjaer 4230). The sound level meter and calibrator were crosschecked against a second sound level meter which was calibrated with its own calibrator. All measurements were made in a double-wall sound booth.

3. Results and discussion

Mean total harmonic distortion and standard deviations for four Radioear B71 bone vibrators are presented in Table 1 for the three test frequencies. Each harmonic distortion measurement is the mean of two determinations made on separate days. At 250 and 1000 Hz the total harmonic distortion and the standard deviation were lower for the acoustic method compared to the electromechanical method. At 500 Hz the harmonic distortion and the standard deviation were lower for the electromechanical measurements. Also shown in Table 1 are the test-retest correlation coefficients for the repeated measures. The correlations, which are nearly identical for the two couplers, indicate good repeatability with both calibration systems. All harmonic distortion values are well below the maximum allowable total harmonic distortion specified by the

Table 1. Total harmonic distortion for four Radioear B71 bone vibrators measured with the acoustic method (AM) and the electromechanical method (EM). Each value is the mean of two measurements. The test-retest correlation coefficients for the paired measurements are shown in the bottom row of the table.

Frequency/Level	Vibrator	AM	EM
250 Hz 20 dB HL	1	1.02	1.46
	2	1.01	2.01
	3	0.88	1.46
	4	0.87	1.51
Mean		0.94	1.61
St.Dev.		0.08	0.27
500 Hz 50 dB HL	1	0.39	0.26
	2	0.31	0.27
	3	0.41	0.26
	4	0.39	0.26
Mean		0.37	0.26
St.Dev.		0.04	0.00
1000 Hz 60 dB HL	1	0.39	0.52
	2	0.29	0.39
	3	0.35	0.43
	4	0.40	0.61
Mean		0.36	0.49
St.Dev.		0.05	0.10
Corr (All Freqs)		0.97	0.99

audiometer standards [5.5% and 6.0% specified by ANSI (1996) and IEC (2012), respectively].

The total harmonic distortion produced by the defective bone vibrator is presented in Table 2. All values exceeded the maximum allowable total harmonic distortion specified in the standards, especially at 250 Hz. At 250 and 500 Hz the harmonic distortion measurements were higher when measured with the electromechanical method compared to the acoustic method.

Harmonic distortion measurements for the prototype vibrator (Radioear B81) are shown in Fig. 1. This device produces significantly lower harmonic distortion than the B71, especially at high input levels. Although all measurements are below the maximum allowable distortion specified in the standards, measurements made with the electromechanical method were higher (except at 500 Hz, 0.5 V) than those made with the acoustic method.

Total harmonic distortion tended to be higher for measurements made with the electromechanical method than with the acoustic method. There are two possible explanations for this difference. The bone vibrator may produce more distortion when working into the higher impedance of the artificial mastoid compared to acoustic coupler. The load offered by the acoustic coupler is the impedance of the air trapped

Table 2. Total harmonic distortion for a defective B71 bone vibrator measured with the acoustic method (AM) and the electromechanical method (EM).

Freq (Hz)	dB HL	AM	EM
250	20	429.0	564.0
500	50	10.1	26.3
1000	60	21.6	15.0

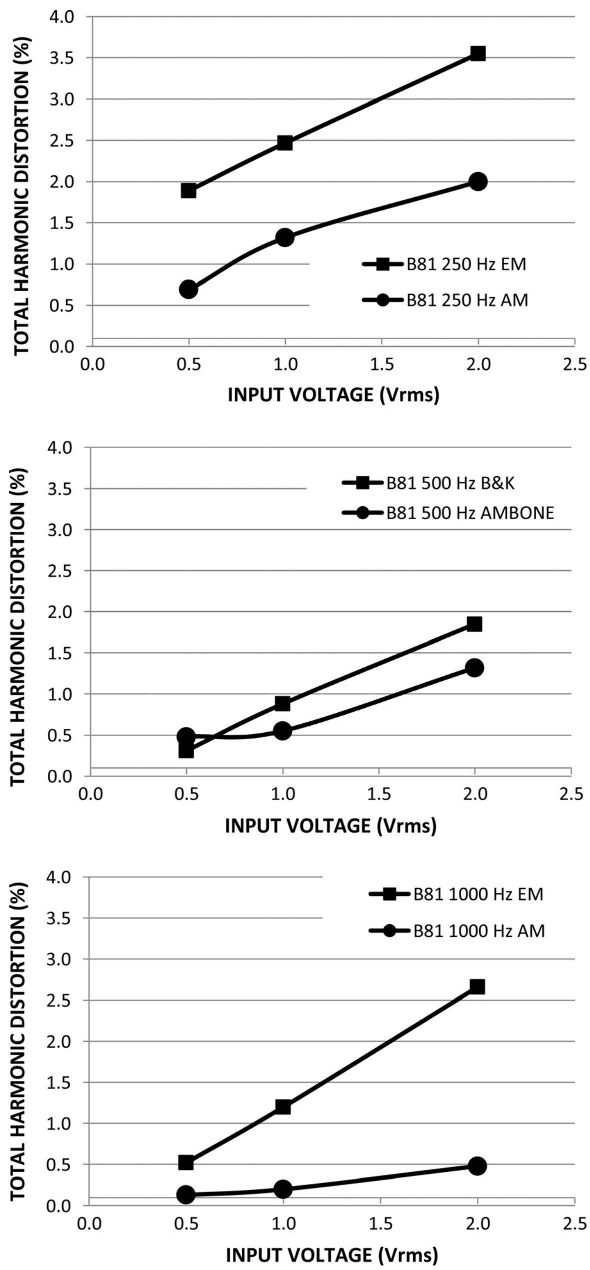

Fig. 1. Total harmonic distortion for a prototype bone vibrator (Radioear B81) at three frequencies measured with the acoustic method (AM) and the electromechanical method (EM).

between the vibrator and the microphone. The mechanical impedance of the B&K artificial mastoid presents a higher load impedance. A second possibility is that the B&K device may produce distortion of its own, which sums with the distortion produced by the vibrator. To explore the effect of the load impedance on the distortion produced by the vibrator, measurements were made with the acoustic coupler under two conditions. In the first condition, the air volume between the bone vibrator and the microphone was 2.49 cm^3, the standard volume of the IEC 60318 coupler (IEC, 2009). In the second condition, the volume was reduced to about 25% of the standard volume

Table 3. Total harmonic distortion for a prototype bone vibrator (Radioear B81) measured with the acoustic method on a standard IEC 60318 coupler and a modified coupler.

		Standard Coupler		Reduced Coupler Volume	
Freq (Hz)	dB HL	dB SPL	THD (%)	dB SPL	THD (%)
250	20	94.7	1.00	99.9	0.53
500	50	107.9	0.30	107.0	0.33
1000	60	106.4	0.27	106.3	0.28

by partially filling the space with clay. The results are shown in Table 3. At 250 Hz, reducing the volume decreased the total harmonic distortion from 1.00% to 0.53%. At 500 and 1000 Hz, differences were minimal (increase of 0.03% and 0.01%). We conclude that increasing the load impedance offered to the bone vibrator does not increase the harmonic distortion. The higher distortion levels obtained with the electromechanical method may be due to distortion in the coupling device itself.

4. Summary and conclusions

Total harmonic distortion measurements with the acoustic method and the standard electromechanical method are similar, but there is a tendency for higher harmonic distortion when measured with the artificial mastoid, especially with the prototype vibrator which is designed to produce lower distortion for high input voltages compared to the commonly used Radioear B71 vibrator. It is possible that the higher distortion is due to distortion introduced by the B&K artificial mastoid itself. Measurements are similarly repeatable with both devices. In the determination of whether the distortion is within the allowable range specified by the standards, the two devices would produce the same conclusions in most cases. These results and those of Margolis and Stiepan (2012) suggest that the acoustic method is a reasonable alternative for bone-conduction calibration of audiometers that could decrease the cost and increase access to calibration.

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