HIGH-FREQUENCY BONE CONDUCTION AUDIOMETRY USING A PIEZOELECTRIC TRANSDUCER

Marie-Claude Gallichan*, Sofia Ravenna*, Christian Giguère*, Tony Leroux*, Lixue Wu and George S.K. Wong****

*** Programme d'audiologie et d'orthophonie, Université d'Ottawa, Ottawa (ON), K1N 6N5**
**** Institute for National Measurement Standards, National Research Council of Canada, Ottawa (ON), K1A 0R6**

1.0 INTRODUCTION

The bone vibrator used with most clinical audiometers, the Radioear B-71, is limited to threshold measurements not exceeding 4 or 6 kHz. A bone vibrator operating at higher frequencies would allow to assess more accurately the exact nature of a hearing loss, conductive or sensorineural, and would provide an alternative to air-conduction transducers for high-frequency audiometry applications. Unfortunately, the frequency response of the B-71 shows steep resonance peaks and sharp drops at high frequencies [1]. The vibration output of electromagnetic bone vibrator devices, like the B-71, also tends to decrease with frequency above 6-8 kHz. This study evaluated a new bone vibrator device based on the piezoelectric effect, developed at the National Research Council of Canada, and designed to overcome these limitations [2].

2.0 METHODS AND MATERIALS

2.1 Subjects

Eight subjects, aged from 18 to 30 years (mean = 24 years), participated. This corresponds to the age range for establishing the reference equivalent thresholds for clinical audiometry under ANSI S3.6-1996 [3]. Subjects had no previous medical history of hearing problems. They all had normal hearing thresholds in the region of 0.25-12 kHz, and normal middle ear function.

2.2 Instrumentation and calibration

Two bone vibrators were under study, the new piezoelectric device from 1 to 12 kHz, and the conventional Radioear B-71 from 1 to 4 kHz for comparison purposes. The stimuli were generated by an Audioscreen Essilor C76FX3 portable extended high-frequency audiometer. The B-71 was connected to the bone vibrator port at the back of the audiometer. In order to supply stimuli up to 12 kHz, the piezoelectric device was connected to one of the two earphone ports at the back of the audiometer. Preliminary tests showed that this arrangement would provide sufficient vibration output to measure bone-conduction (BC) thresholds for normal subjects.

The two bone vibrators were calibrated using a Brüel & Kjær Type 4930 Artificial Mastoid in compliance to the general test procedures from ANSI S3.6-1996. The force sensitivity level of this artificial mastoid is specified up to 10 kHz by the manufacturer. For the calibration of the piezoelectric device at 12 kHz, the force sensitivity curve was extrapolated from 10 to 12 kHz. In a previous study [1], the force sensitivity level of the Brüel & Kjær Type 4930 Artificial Mastoid was shown to increase smoothly from 8 to 16 kHz.

During BC threshold measurements, narrow-band masking noise was applied to the non-test ear of the subjects using a GSI-10 clinical audiometer and a Telephonics TDH-50P earphone. All calibration and threshold measurements took place in an audiometric room at the University of Ottawa. The ambient noise met the requirements of ANSI S3.1-1991 [4].

2.3 Procedures

All BC threshold measurements were obtained using the Hughson-Westlake ascending/descending method with a step size of 3 dB. Only the right ear of the subjects was tested using a mastoid placement of the bone vibrators. The B-71 vibrator was tested at 1, 2, 3 and 4 kHz. In addition to these frequencies, the piezoelectric vibrator was also tested at 6, 8, 10 and 12 kHz. For each vibrator, thresholds were obtained with and without an earplug occluding the right ear. These two conditions permitted to test whether acoustic radiation from the shell of the vibrators could interfere with BC threshold measurements. In all conditions, the non-test left ear was masked at a level of 30 dB HL. Finally, for two of the subjects, BC threshold measurements were repeated 16 times for each of the two vibrators under the condition of occluded test ear. The bone vibrator was refitted each time on the subject's mastoid. This permitted to assess the intra-subject threshold variability due to vibrator placement and behavioural response.

3.0 RESULTS AND DISCUSSION

Based on Student t-test statistical analyses of the unoccluded BC threshold measurements, there was no significant difference ($p > 0.05$) between the two vibrators at 1, 2 and 3 kHz. At 4 kHz, a significant difference ($p = 0.004$) was observed between the two vibrators, the B-71 yielding a threshold value well above (15.8 dB) the reference equivalent threshold force level (RETFL) from ANSI S3.6-1996. In contrast, the piezoelectric vibrator yielded a threshold value only slightly lower (-3.7 dB) that the RETFL.

There was no statistical difference in threshold measurements between the occluded and unoccluded test ear conditions for the B-71 vibrator at 2, 3 and 4 kHz. At 1 kHz, occluded thresholds were 10.8 dB lower on average than unoccluded thresholds and the difference was significant ($p = 0.001$). For the piezoelectric vibrator, there was no statistical difference at any frequency from 1 to 12 kHz. However, at 1 kHz the piezoelectric device showed the same tendency as the B-71 for lower occluded thresholds. The difference was 6.0 dB and it almost reached statistical significance ($p = 0.07$). The threshold differences at 1 kHz are consistent with the reported occlusion effect of 7.6 dB for earplugs under an average insertion in the ear canal [5]. Altogether, these results confirm that acoustical radiations are negligible for the two bone vibrators and that both can be used for BC threshold measurements with the test ear unoccluded.

Figure 1 compares the mean unoccluded BC threshold values obtained in this study for the Radioear B-71 and the piezoelectric device to the RETFLs from ANSI S3.6-1996, and to the median unoccluded BC threshold values reported by Hallmo et al. [6] for males and females in the age group 18-24 years using the Präcitronic KH70 electromagnetic transducer. With the exception of the B-71 at 4 kHz, the reported thresholds are similar. Over the 1-4 kHz region, the piezoelectric device provided a better match to the RETFLs from ANSI S3.6-1996 than the B-71. Above 4 kHz, the piezoelectric device yielded slightly lower thresholds than the RETFLs from ANSI or the data from Hallmo et al. by about 3 to 8 dB.

Tables I and II list the standard deviation for the 16 repetitions of BC measurements carried out by two subjects. In the 1-4 kHz region, the variability in threshold measurements is very similar for the two bone vibrators. The main exceptions are the larger standard deviation with the B-71 at 3 kHz for subject 1, and the larger standard deviation with the piezoelectric device at 1 kHz for subject 2. For both vibrators, the intra-subject variability does not exceed the commonly accepted clinical test-retest threshold criterion of ± 5 dB.

In summary, the new piezoelectric transducer is suitable to measure unoccluded BC thresholds from 1 kHz up to at least 12 kHz for normal young adults. Further tests are needed with older subjects and hearing-impaired individuals to establish the maximum hearing levels at which the piezoelectric transducer can be used.

REFERENCES

[1] Richter, U. and Frank, T. (1985). "Calibration of bone vibrators at high frequencies."Audiol. Acoust. 24, 52-62.

[2] Wong, G.S.K., Wu, L., Kunov, H. and Madsen, P.B. (1996). "A wide-band piezoelectric transducer for otoacoustic emission applications." Proc. of the Int. Congress on Noise Control Engineering (Liverpool, UK), Vol. 5, 2565-2569.

[3] ANSI S3.6-1996. *American National Standard Specification for Audiometers* (American National Standards Institute, New York).

[4] ANSI S3.1-1991. *American National Standard Maximum Permissible Ambient Noise Levels for Audiometric rooms* (American National Standards Institute, New York).

[5] Schroeter, J. and Poesselt, C. (1986). "The use of acoustical test fixtures for the measurement of hearing protector attenuation. Part II." J. Acoust. Soc. Am. 80, 505-526.

[6] Hallmo, P., Sundby, A. and Mair, I.W.S. (1994). "Extended high-frequency audiometry." Scand. Audiol. 23(3), 165-170.

Table I: Standard deviation (dB) for 16 BC threshold measurements under occluded test ear condition (Subject 1)

Frequency (Hz)	Radioear B-71	Piezoelectric device
1	3.2	4.0
2	2.1	2.0
3	5.1	2.1
4	2.1	3.2
6	-	2.2
8	-	2.9
10	-	3.4
12	-	2.8

Table II: Standard deviation (dB) for 16 BC threshold measurements under occluded test ear condition (Subject 2)

Frequency (Hz)	Radioear B-71	Piezoelectric device
1	2.5	5.0
2	3.0	3.7
3	3.4	2.8
4	2.7	2.9
6	-	3.2
8	-	4.0
10	-	3.5
12	-	3.2

[Work conducted under a collaborative research agreement between the University of Ottawa and the National Research Council of Canada]

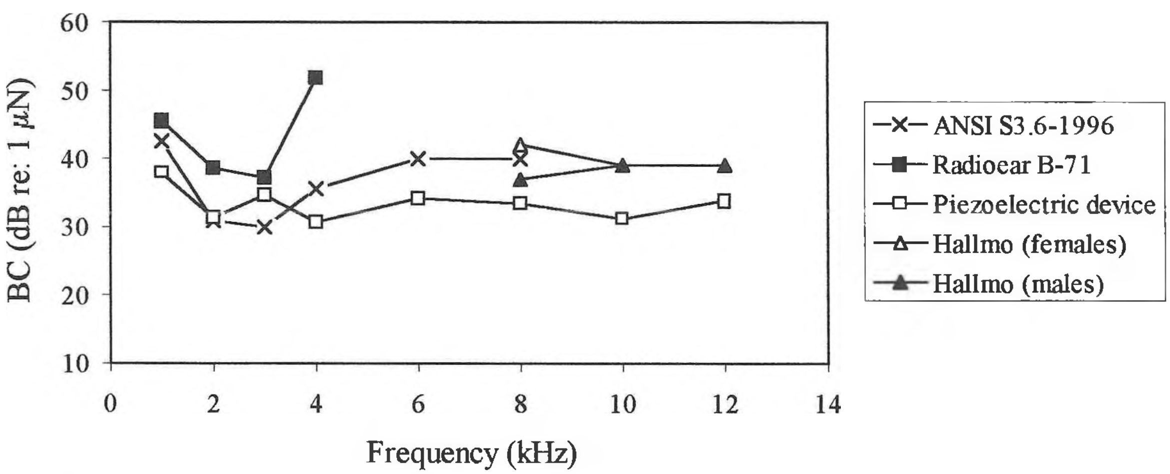

Figure 1: Comparison of BC thresholds from different sources and devices: ANSI S3.6-1996 (RETFLs), Radioear B-71 (n=8), Piezoelectric device (n=8), and Pracitronic KH70 device from Hallmo et al. (1994).