Diagnostic hearing investigations of patients with suspected hearing loss comprises both air and bone conduction threshold testing. Bone conduction hearing threshold testing reveals the degree of sensorineural hearing loss and is performed with a bone vibrator attached on the skin over the mastoid portion of the temporal bone or the forehead to electro-mechanically induce vibrations into the skull to stimulate the cochlea. Together with air conduction thresholds, a patient’s air to bone threshold difference (air-bone gap) can aid in determining the type of hearing loss and to choose an adequate hearing (re)habilitation.

The B71 from Radioear (Radioear Corporation, Pennsylvania, USA) has been the most widely used audiometric bone vibrator since the 1970s (Gallifchan et al, 1998). Other similar devices developed over the years are, from Radioear, the B70 and the B72, and from Grannahrt Præcitronic GmbH, Germany, the KH70. In comparison with the B71, the B70 does not have the same circular attachment area and the B72 is heavier because of an extra mass added to achieve higher output levels at low frequencies (Henry & Letowski, 2007). The KH70 is considered to have good linearity with a flatter frequency response than the Radioear devices that are all characterized by three distinct resonance peaks (Richards & Frank, 1982). Furthermore, the KH70 radiates less airborne sound (Frank & Crandell, 1986), but it is large and heavy, which makes it difficult to attach on the mastoid without touching the ear (Håkansson, 2003; Stenfelt & Goode, 2005).

The main weakness of the B71 is that it produces high harmonic distortion at low frequencies (Dirks & Kamm, 1975; Dolan & Morris, 1990; Parving & Elbering, 1982). This is a serious problem that explains why bone conduction hearing thresholds in practice are rarely tested below 500 Hz. In a study by Håkansson (2003), the balanced electromagnetic separation transducer (BEST) principle was first introduced. It promised to give an improved low frequency performance with a highly reduced level of harmonic distortion that could not be achieved by the conventional variable reluctance type transducers like the one that is used in the B71. In a collaboration between Ortofon A/S, Nakskov, Denmark, and Chalmers University of Technology, Gothenburg, Sweden, the BEST principle has been further optimized. Using the BEST principle, static forces are counterbalanced so that nonlinear distortion forces are reduced and maximum hearing levels can be increased. The first bone vibrator...
for audiometric testing based on the BEST principle and adapted for serial production, was recently developed under the trade name Radioear B81. It comprises a new casing, electrostatic discharge (ESD) safe contacts, and a shock resistance design that can be beneficial for its application in audiology. In a study by Ginter and Margolis (2013), one B81 prototype bone vibrator was compared with five B71 bone vibrators and it was found that the B81 generated less distortion at low frequencies.

As the BEST principle offers new features to improve bone conduction audiometry, it is also being used in transducers for other applications. One such application is in a new bone conduction hearing implant system for rehabilitation of patients with mixed or conductive hearing loss, see Eeg-Olofsson et al (2014) and Reinfeldt (2013), one B81 prototype bone vibrator was compared between five B71 bone vibrators and it was found that the B81 generated less distortion at low frequencies.

The aim of this study was to evaluate the electro-acoustic performance of the new audiometric bone vibrator Radioear B81 and to compare it with the conventional Radioear B71. In particular, the frequency response, total harmonic distortion (THD), maximum hearing level, and electrical impedance were investigated.

Method

Technical design of bone vibrators

A detailed description of the dynamic operation of the conventional transducer as well as the BEST transducer is given in Håkansson (2003) and is summarized below.

Radioear B71

The conventional bone vibrator B71 comprises an electromagnetic variable reluctance transducer that transforms electromagnetic energy into mechanical vibrations as magnetic fields with alternating direction force a small air gap to change size in a harmonic motion. The cross-sectional view of the variable reluctance transducer in the B71 is shown in Figure 1. A permanent magnet inside the transducer is fixed on an armature suspended to the yoke by the use of a suspension spring. The static magnetic flux “Φ0” of the permanent magnet creates a static attraction force in the air gap between the armature and the yoke, but due to its compliant nature, the suspension spring counteracts this force and maintains the air gap. By driving a time-varying current “i(t)” through a pair of twin coils, wound around two yoke arms, the dynamic flux “Φ ∼” is induced and the transducer vibrates with the same frequency as the current. Unfortunately, this type of transducer has inherently high harmonic distortion when generating low frequency vibrations, since the force is nonlinearly related to the dynamic flux. To reduce the nonlinear distortion and achieve a highly efficient electro-mechanical transmission, the static magnetic flux “Φ0” creating the static force in the air gap needs to be much higher than “Φ ∼”. This requires a stiff opposing spring and a large counteracting mass that together form a resonance in the frequency response at the frequency “f0” according to

\[ f_0 = \frac{1}{2\pi\sqrt{m/C}} \]  

(1)

where “C” is the compliance of the spring and “m” the counteracting mass. To compensate for a stiff spring, using Equation (1), a bigger counterweight mass can be used, as in the B72 design, but this will increase the size and weight of the transducer. A relatively low resonance frequency in bone conduction is desirable when hearing tests incorporating frequencies down to 250 Hz are requested. For calibration purposes, resonance peaks should be avoided at the audiometric frequencies, since peak levels are likely to vary. The low resonance frequency peak should therefore be close to the midpoint between 250 and 500 Hz to achieve a high and stable output at the lowest frequencies.

The total vibrating force “Ftot” of the transducer is proportional to the total magnetic flux in the air gap squared, which is the sum of the static and the dynamic flux squared, resulting in

\[ F_{tot} \propto (\Phi_0 + \Phi \sim)^2 = \Phi_0^2 + 2\Phi_0\Phi \sim + \Phi \sim^2 \]  

(2)

where the quadratic flux “Φ2 ∼” is the nonlinear term that causes distortion. A simplified model of the principle design of a variable reluctance transducer is shown in Figure 1, where the pathways of the fluxes are outlined by the solid and dashed lines for static and dynamic flux, respectively, and leakage fluxes have been neglected.

Radioear B81

The new bone vibrator Radioear B81 from Radioear Corporation, Pennsylvania, USA, comprises a BEST transducer that, like the variable reluctance transducer in the B71, transforms electromagnetic power into mechanical vibrations, but by the use of a different topology with multiple air gaps. In the BEST principle, four permanent
magnets and inner and outer air gaps create a force balance, see Figure 2. A dynamic flux \( \Phi \sim \Phi_0 \) is induced by a time-varying electric current, driven through a single coil wound around a bobbin core in the center of the transducer. From the relation that the force is proportional to the magnetic flux squared, the force in each air gap can be calculated and the total vibrating net force of the transducer found by adding these forces together, see Equation (3). In the inner air gaps, “B” and “C”, the total magnetic flux is comprised by the static magnetic flux produced by the permanent magnets and the dynamic flux from the coil, while the dynamic flux is zero in the outer air gaps, “A” and “D”. Due to symmetry in the design, the air gap forces can be calculated from “A” to “D” and added together at one side, then multiplied by a factor of 2 to find the resulting total vibrating net force of the transducer, i.e. \( F_{\text{tot}} = 2(F_A + F_B + F_C + F_D) \) (3)

where approximately half of the dynamic flux “\( \Phi \) ” flows through each side and each permanent magnet contributes with a static flux “\( \Phi_0 \)”. This makes the inner air gaps interact constructively as “B” always increases with the same force as “C” decreases with and vice versa. The forces in the air gaps can be approximated by the following equations:

\[ F_A = -F_D \propto \Phi_0^2 \]  
(4)

\[ F_B \propto \left( \Phi_0 - \frac{\Phi_0}{2} \right)^2 \]  
(5)

and

\[ F_C \propto -\left( \Phi_0 + \frac{\Phi_0}{2} \right)^2 \]  
(6)

Finally,

\[ F_{\text{tot}} \propto 2\left( \Phi_0^2 + \left( \Phi_0 - \frac{\Phi_0}{2} \right)^2 - \left( \Phi_0 + \frac{\Phi_0}{2} \right)^2 - \Phi_0^2 \right) = 4\Phi_0 \Phi_0 \]  
(7)

From Equations (3) to (7) it is obvious that this force balance cancels both the quadratic flux and the bias flux. This gives the B81 higher linearity than the B71 and with that, a lower harmonic distortion. However, this is an approximated model where nonlinear characteristics of the soft iron and spring material are excluded. Furthermore, it has been assumed that there is no dynamic flux in the outer air gaps and that those only serve as a magnetic pathway for the static flux from the permanent magnets. In fact, the influence of parasitic fields and fringe fields are important considerations. Outside the balanced position where the inner air gaps have different length, a small part of the static and dynamic flux will flow through either the core of the yoke or the permanent magnet and superimpose in other air gaps. Fortunately, the parasitic fields through the permanent magnet will constructively add to the generated dynamic force and with an appropriate choice of magnetic materials and air gap lengths, the impact from parasitic fields can be kept relatively small.

The B81 has been designed to replicate the frequency response and electrical impedance of the B71 so both bone vibrator types can be used in the same audiometer. Other physical parameters such as size and weight of the two types are shown in Table 1 and the external view in Figure 3. To summarize their mechanical data, the B81 has a little lower profile than the B71, but in practical sense they have the same weight and size as well as a circular attachment surface area of 1.75 cm².

Table 1. Mechanical data for the B71 and the B81 bone vibrators.

<table>
<thead>
<tr>
<th>Bone vibrator</th>
<th>Height</th>
<th>Length</th>
<th>Width</th>
<th>Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>B71</td>
<td>18.9 mm</td>
<td>31.6 mm</td>
<td>18.2 mm</td>
<td>19.9 g</td>
</tr>
<tr>
<td>B81</td>
<td>16.0 mm</td>
<td>31.7 mm</td>
<td>18.2 mm</td>
<td>20.0 g</td>
</tr>
</tbody>
</table>

Measurement setup

The measurement setup used in this study is shown in Figure 4. Frequency response, THD, maximum hearing level, and electrical impedance were measured for six B71 and six B81 bone vibrators attached to an artificial mastoid B&K 4930 (Bruel & Kjær Sound & Vibration Measurement A/S, Denmark). Each of the tested bone vibrators was picked as consecutive samples from production. During all measurements, the bone vibrators were applied with a static force of 5.4 N according to ISO 389-3, and the environmental temperature was 23 ± 0.5°C as specified in IEC 60645-1.

The measurements were controlled using LabVIEW 2011 (National Instruments Corporation, Texas, USA) software. An Agilent 33220A Function/Arbitrary Waveform Generator (Agilent Technologies Inc., California, USA) was remotely controlled to apply the input voltage “\( V_{in} \)”, fed via a power amplifier LPA01 Laboratory Power Amplifier (Newtons4th Ltd., UK) to the bone vibrator. The output voltage from the artificial mastoid was fed via a charge amplifier B&K 2635 and measured using NI ELVIS II (National Instruments Corporation, Texas, USA) hardware. For signal monitoring purposes, a PicoScope 5203 PC Oscilloscope (Pico Technology, UK) was used to measure the input voltage to the bone vibrator under test. To protect the bone vibrator from heating up at high signal levels, a switch was used to shorten the operation time. For further protection, a low power resistor “\( R \)” of 5 Ohms was connected in series between the bone vibrator and the switch. The applied input voltage to the bone vibrator was measured after this resistor not to influence the measurement. The resistor was also used in the electrical impedance measurement to measure the supply current “\( i(t) \)” to the bone vibrator. For verification of the LabVIEW program, the same measurements were also made using an Agilent 35670A FFT Dynamic Signal Analyzer (Agilent Technologies, Inc., California, USA).

Pad correction

The bone vibrators delivered a dynamic force “\( F_{in} \)” to the surface of the rubber pad of the artificial mastoid when driven by an input voltage “\( V_{in} \)”, see Figure 4. This force is related to the output voltage “\( V_{out} \)”, from a gauge placed under the pad, by a pad correction “\( P(\phi) \)” as defined in Equation (8).

Figure 3. External view of the B71 (left) and the B81 (right) bone vibrators.
The pad correction "$P(j\omega)$" is shown in Figure 5 and was obtained using the impedance head B&K 8000 and mini shaker B&K 4810, together with two charge amplifiers B&K 2651 to amplify the force and acceleration signals according to the method described in the product data sheet of the artificial mastoid.

**Post processing**

The output force of a bone vibrator is commonly expressed in force level $\text{Fin}$ in decibels relative to 1 mN or in hearing level in decibel (dB HL). The latter will include an additional calculation step where the reference equivalent threshold force levels (RETFLs) specified in ISO 389-3 as normal hearing thresholds are subtracted to the measured force levels, i.e.

\[
\text{Hearing Level} = \text{Fin} - \text{RETFL} \ [\text{dB}] \tag{9}
\]

Force and hearing level compensations were performed both in real-time and after post processing for monitoring of distortion and signal levels during the measurements as well as to collect compensated and uncompensated data for further analysis and documentation.

**Frequency response of the bone vibrators**

The frequency response $G(j\omega)$ of each bone vibrator was measured as the force $\text{Fin}$ at the pad surface over the voltage $\text{Vin}$ to the bone vibrator from 100 Hz to 10 000 Hz and at an input voltage of 1 V RMS. That is

\[
G(j\omega) = \frac{\text{Fin}}{\text{Vin}} \tag{10}
\]

where $\text{Fin}$ was calculated from Equation (8) after measuring $\text{Vout}$ and dividing by $P(j\omega)$.

**Total harmonic distortion**

THD is a measure of the amount of distortion power in percent of a harmonic signal relative to the total signal power. Harmonic distortion arises as peaks at multiple frequencies of the fundamental frequency in the spectrum of the output voltage from the artificial mastoid. The THD was calculated according to the standard IEC 60268-3 and from the RMS magnitude of the linear spectrum of the dynamic force level $\text{Fin}$ at the rubber pad surface (after pad correction) as

\[
\text{THD} = \sqrt{\frac{H_2^2 + H_3^2 + \ldots + H_n^2}{H_1^2 + H_2^2 + H_3^2 + \ldots + H_n^2}} \times 100\% \tag{11}
\]

where $H_n$ is the magnitude of the $n^{th}$ harmonic in the linear spectrum of $\text{Fin}$. The RMS magnitude of the fundamental frequency is $H_1$, and $n$ is the number of harmonics included in the calculation. Up to five harmonics, including the fundamental frequency, have been used in this study, but harmonics exceeding frequencies of 10 000 Hz, which are outside the range of the artificial mastoid were set to zero and not considered. The highest fundamental frequency that THD was calculated for was therefore 5000 Hz with only the second harmonic of 10 000 Hz included in the calculation. The THD was calculated from the peaks of the harmonics from the audiometric frequencies when the bone vibrators were driven by...
The New Bone Vibrator Radioear B81

1 V_{RMS}. It was verified that the distortion power originating from the input signal was negligible relative to the distortion power generated by the bone vibrators under test.

**Maximum hearing level**

By successively increasing the input voltage, the maximum hearing level was obtained at the hearing level where either the THD became 6% (specified in IEC 60645-1) or the input voltage reached 6 V_{RMS} (industry recommended maximum operation voltage), whichever came first.

**Electrical impedance**

The electrical impedance of each transducer was calculated according to Equation (12) by measuring the frequency response \( \frac{V_m}{V_e} \) when the bone vibrator was connected in series with the protection resistor \( R \), see Figure 4.

\[
Z_f = \frac{V_m}{R(t)} = \frac{V_m}{V_e} = R \frac{V_e}{1 - \frac{V_e}{V_i}} \tag{12}
\]

**Results**

**Frequency response**

The mean frequency response of six B71 and six B81 bone vibrators, respectively, are shown in Figure 6. They both have three relatively damped resonance peaks and are very similar except in the mid frequencies between the low frequency and mid frequency peak, where the B81 at the most is 5.5 dB higher than the B71. The three peaks, from the lowest to the highest frequency, occur at about 375 Hz, 1450 Hz, and 4000 Hz for the B71; and at 425 Hz, 1300 Hz, and 4125 Hz for the B81, respectively.

**Total harmonic distortion**

The mean of the THD for both bone vibrator types when driven by 1 V_{RMS} are shown in Figure 7. The main difference occurs at frequencies up to 1000 Hz with the maximum difference at low frequencies. At the lowest audiometric frequency of 250 Hz, the THD is 28.07 ± 5.39% for the B71 and only 1.88 ± 0.41% for the B81. At frequencies from 1000 Hz and above, the THD is less than 2% for both bone vibrator types.

The maximum hearing levels for B71 and B81 are shown in Figure 8 together with the minimum required hearing levels as specified in IEC 60645-1. Below 1500 Hz, the B81 reaches 10.7 to 22.0 dB higher levels than the B71 with the maximum difference at 250 Hz. Above 1500 Hz, the performance is very similar for both bone vibrator types except at 2000 Hz where B81 is 4.8 dB higher; and at 8000 Hz where it is 3.2 dB lower. The B81 fulfills the IEC 60645-1 requirements between 250 and 8000 Hz by a margin of 6.5 to 25.1 dB. The B71 was below standard values by 14.4 dB at 250 Hz and fulfills the standard only between 500 Hz and 8000 Hz by a margin of 1.0 to 21.6 dB.

**Discussion**

The electro-acoustic performance of the new bone vibrator Radioear B81 and the conventional Radioear B71 were compared by measuring frequency response, THD, maximum hearing level, and electrical impedance for six devices of each type. Two tailed student’s t-tests were performed to see if any statistically significant differences exist between the two bone vibrator types, with the null hypothesis that their electro-acoustic performances were equal.

**Electrical impedance**

The electrical input impedances of both bone vibrator types are shown in Figure 9. The curves are very similar for both devices except above 2000 Hz where they start to differ with the greatest difference of 15.9 Ohm at 10 000 Hz. The electrical resistance at DC of the B71 and the B81 were measured using a multimeter and found to be 3.0 ± 0.1 Ohm and 3.3 ± 0.1 Ohm, respectively.

**Figure 6.** The mean frequency response of six B71 and six B81, respectively, obtained at an input voltage of 1 V_{RMS}. The magnitude is given in decibels relative the 1 µN/V.

**Figure 7.** The mean value of the total harmonic distortion (THD) of six B71 and B81, respectively, when the bone vibrators are driven by an input voltage of 1 V_{RMS}, calculated from the linear spectrum of the output force levels.

**Figure 8.** The mean value of the maximum hearing level in decibels that was achieved by six B71 and B81, respectively, without exceeding a THD of 6% or at a maximum input voltage of 6 V_{RMS}, whichever comes first. The dashed line shows the minimum hearing level required in compliance with IEC 60645-1.
The B81 was designed to replicate, as close as possible, the characteristic three damped peaks in the frequency response of the conventional B71. The rationale for this was that the B81 should be compatible with the same audiometers as is used for the B71 today. It was found from the measurements that the frequency response was almost identical for the two types except a difference in the mid frequencies (α = 0.01) where B81 was at the most 5.5 dB higher. This difference in frequency response should either be directly calibrated for in the audiometer or indirectly compensated for in the results from bone conduction thresholds measurements.

The electrical impedances are very similar for the two types, particularly below 2000 Hz, which can be seen in Figure 9. With similar frequency response and electrical impedance, the B81 is compatible with same audiometer types as are used for the B71 today. For the audiometric frequencies in Table 2, the greatest standard deviation with same audiometer types as are used for the B71 today. For the frequency response and electrical impedance, the B81 is compatible particularly below 2000 Hz, which can be seen in Figure 9. With similar frequency response and electrical impedance, the B81 is compatible with same audiometer types as are used for the B71 today. For the audiometric frequencies in Table 2, the greatest standard deviation of the frequency response results was found to be ±1.7 dB at 8000 Hz for B71, and ±1.2 dB at 6000 Hz for B81.

Most importantly, the THD was found to be considerably lower for B81, especially at frequencies up to 1000 Hz. It was measured for both bone vibrator types when the input voltage was 1 V\textsubscript{RMS}. With this reduction in THD, the B81 was found to offer 10.7 to 22.0 dB higher maximum hearing levels for frequencies below 1500 Hz without exceeding (1) the limiting 6% in THD nor (2) an input voltage of 6 V\textsubscript{RMS}. The greatest improvement was 250 Hz, where the maximum hearing level for the B81 (mean 52.6 ± 0.8 dB HL) meets the IEC 60645-1 requirements (45 dB HL), whereas the B71 (mean 30.6 ± 2.5 dB HL) was below standard, see Figure 8. For frequencies above 1500 (B81) and 3000 Hz (B71), the THD was less than 6% when the input voltage was 6 V\textsubscript{RMS}. This means that distortion limits the maximum hearing level of the B71 in a wider frequency range than it does for the B81. The audiometric frequency with greatest standard deviation was observed in the THD of B71 at 250 Hz (± 5.39%), but was relatively small compared to the mean value (28.07%).

In audiological diagnostics, distortion results should be investigated in terms of hearing levels rather than in force levels. Reference equivalent threshold force level (RETFL) values specified in IEC 389-3 (right-most column Table 2), have therefore been used to transform output force levels to hearing levels according to Equation (9). When the force levels of the harmonics included in the THD calculation in Figure 7 are compensated for the actual hearing sensitivity, it is obvious that distortion at low frequencies is a serious problem, however significantly improved by the B81, see Figure 10. When the distortion power becomes as high as the fundamental power, the THD is about 71%, which was calculated from Equation (11). This occurs at low frequencies below 250 Hz and 110 Hz for B71 and B81, respectively. A contradictory phenomenon to the effect of hearing level compensated THD might be that sensorineural hearing loss often is of ski-slope type i.e. higher distortion harmonics will be less audible than the harmonic of fundamental frequency.

The circular attachment surface of both B71 and B81 is 1.75 cm², meaning that the same force levels are required to generate the same hearing levels under the assumption that the RETFL values are the same for the two bone vibrator types. In the IEC 389-3 standard, the RETFL values are based on measurements from the B71. If those measurements were affected by the distortion at low frequencies, the B81 can be used to improve the accuracy of RETFL values or possibly require separate RETFL values.

**Conclusions**

The B81 was designed to approximate the frequency response and electrical impedance of the B71 in order to be compatible with the same audiometers, which was confirmed in this study. By using the

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**Table 2.** Summary of frequency response, total harmonic distortion, and maximum hearing level at the audiometric frequencies. The values are the mean with standard deviations for six devices of each type (*). A star (*) indicates that the B81 is statistically better than the B71 (α = 0.01).

<table>
<thead>
<tr>
<th>Frequency (Hz)</th>
<th>Frequency response (magnitude)</th>
<th>THD @ 1 V\textsubscript{rms} (%)</th>
<th>Maximum hearing level (dB HL) @ 6% THD or 6 V\textsubscript{rms}</th>
<th>RETFL (dB re. 1 \textmu N)</th>
</tr>
</thead>
<tbody>
<tr>
<td>250</td>
<td>111.7 ± 0.7</td>
<td>1.88 ± 0.41*</td>
<td>28.07 ± 5.39</td>
<td>52.6 ± 0.8*</td>
</tr>
<tr>
<td>500</td>
<td>123.5 ± 0.4*</td>
<td>0.87 ± 0.20*</td>
<td>5.52 ± 0.83</td>
<td>74.6 ± 0.4*</td>
</tr>
<tr>
<td>750</td>
<td>118.8 ± 0.3*</td>
<td>1.75 ± 0.19*</td>
<td>8.66 ± 1.60</td>
<td>78.9 ± 0.9*</td>
</tr>
<tr>
<td>1000</td>
<td>118.5 ± 0.4*</td>
<td>1.36 ± 0.18*</td>
<td>3.30 ± 0.66</td>
<td>86.6 ± 1.1*</td>
</tr>
<tr>
<td>1500</td>
<td>117.2 ± 0.6*</td>
<td>0.86 ± 0.24</td>
<td>1.05 ± 0.11</td>
<td>93.2 ± 0.7*</td>
</tr>
<tr>
<td>2000</td>
<td>107.9 ± 0.6</td>
<td>0.13 ± 0.03</td>
<td>1.91 ± 0.41</td>
<td>90.9 ± 0.3*</td>
</tr>
<tr>
<td>3000</td>
<td>101.0 ± 0.3</td>
<td>0.19 ± 0.07</td>
<td>0.50 ± 0.08</td>
<td>85.8 ± 0.2</td>
</tr>
<tr>
<td>4000</td>
<td>105.1 ± 0.2</td>
<td>0.26 ± 0.10</td>
<td>0.24 ± 0.10</td>
<td>85.1 ± 0.3</td>
</tr>
<tr>
<td>6000</td>
<td>89.7 ± 1.2*</td>
<td>87.6 ± 0.9</td>
<td>63.1 ± 0.6</td>
<td>62.8 ± 0.7</td>
</tr>
<tr>
<td>8000</td>
<td>80.7 ± 0.6*</td>
<td>83.5 ± 1.7</td>
<td>56.5 ± 1.0</td>
<td>59.7 ± 2.0</td>
</tr>
</tbody>
</table>
new transducer principle BEST, the B81 was expected to have lower harmonic distortion and achieve higher maximum hearing levels. It was found that the THD was considerably lower for the B81 up to 1000 Hz and mainly unchanged above. The maximum hearing levels for the B81 were found to be 10.7 to 22.0 dB higher than for the B71 at frequencies below 1500 Hz and unchanged above. The B81 met the IEC 60645-1 requirements at all frequencies, but the B71 produced an output that was below the standard at 250 Hz.

In summary:

- The B81 has generally lower distortion and allows higher hearing levels than the B71 below 1500 Hz
- Bone conduction threshold testing at 250 Hz can now be appropriate for routine diagnostics

These results indicate that less distortion will affect the measurements when using B81 as an aid for diagnosing hearing loss. In future studies, the acoustically radiated noise from the bone vibrator casing, static force dependence, drop testing, and tactile thresholds will be investigated.

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Declaration of interest: Leif Johannsen is engaged with Ortofon A/S who manufactures the B81 for Radioear Corporation. Bo Håkansson is the inventor of some BEST patents. The authors report no other conflict of interest.

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