



Improving Accuracy and Reliability of Hearing Tests: Measurement Standards for Audiometric Devices

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Pure-tone audiometry, using an audiometer, is the fundamental hearing test for diagnosing hearing loss. The requirements of the devices and the detailed process for calibrating the related equipment are described in international standards. However, traceable calibration and uncertainty evaluation processes are not widely accepted or applied to the qualification and maintenance of audiometric equipment. Here, we briefly review standard measurement systems for audiometric devices and introduce their calibration procedures. The uncertainty of each calibration process was investigated, and its impact on hearing test results was considered. Our findings show that the traceability of each procedure can be secured, satisfying the uncertainty requirement and being sufficiently smaller than the permissible deviation from the audiometer requirement. To guarantee the objectivity and reliability of hearing tests and maintain low uncertainty, close cooperation and mutual understanding between the metrology field and the medical community are necessary.

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Introduction

Pure-tone audiometry, using an audiometer, is the most basic test for diagnosing hearing loss [1]. The audiometer was designed to present designated auditory stimuli to the subjects and determine their awareness of the stimuli. Therefore, the accuracy of the output response to the stimuli is crucial for reliability of the test.

To guarantee the value of the measured quantity, traceabil-

ity is necessary to ensure connectivity with international systems of units. The metrology system provides a basis to ensure the international equivalence of measurement results. From this reason, the consultative committee of the Bureau International des Poids et Mesures (BIPM) recommends establishing and managing a standard system for important measurement instruments for each base quantity. Audiometry devices are also listed in the service classification of the Consultative Committee for Acoustics, Ultrasound, and Vibration. Therefore, traceable calibration of audiometry devices should be performed according to the corresponding international standards. Although device requirements and the detailed calibration process for the related equipment are well

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described in international documentary standards, traceable calibration and uncertainty evaluation processes are still not widely accepted or applied to the qualification process for audiometric equipment.

Therefore, in this study, we briefly reviewed the standard measurement systems for audiometric devices and their calibration procedures. In addition, we investigated the uncertainty of each calibration process and its effect on the hearing test results.

Standard System and Traceability Chain for Audiometry

The role of a standard measurement system is to provide a connection to the definition of a unit and to make it traceable. Traceability is defined as “*Property of a measurement result whereby the result can be related to a reference through a documented unbroken chain of calibrations, each contributing to the measurement uncertainty* [2].” Therefore, the traceability chain can be implemented by connecting the calibrations.

The primary standards of unit are implemented by the BIPM and National Metrology Institutes (NMIs) of each economy and the international equality is validated via comparison between the NMIs which is called “Key Comparison.” The traceability is transferred from this primary standard to other measurement devices by applying a calibration process.

Audiometry devices can be categorized into audiometers and ear simulators [3]. Audiometers are to deliver the stimuli and ear simulators are to calibrate the response level of the audiometer. Ear simulators are couplers designed to simulate the approximated overall response of the human auditory system [4-6]. An ear simulator for bone-conduction stimuli is called a mechanical coupler [6] and it simulates the mechanical impedance of the human mastoid position.

Fig. 1 presents the traceability chain of the audiometer for air-conduction response level. An air-conduction audiometer is used to deliver sound stimuli and is categorized as “Sound-in-Air.” The primary standard of this branch is the laboratory standard (LS) microphone [7] wherein the sound pressure level is indirectly determined by the sensitivity of the LS microphone [8]. As a working standard (WS), other types of reference microphones are also defined in IEC 61094-4 [9] and are calibrated using an LS microphone as a reference [10]. The ear simulator is calibrated using WS microphones, and the output level of the audiometer is calibrated by measuring the output using a calibrated ear simulator [4]. Here, the device used to read the output, the sound level meter [11], or other types of voltage measurement instruments are applied, and should also be calibrated based on the proper correspond-

ing standards.

Fig. 2 shows the traceability chain of the bone-conduction response level of the audiometer. The bone conduction transducer delivers a dynamic force consisting of vibration acceleration and mass. Length (m) and time (s) are the primary standards of vibration (acceleration) and a laser interferometer is used for the primary calibration of a standard accelerometer [12]. The WS class accelerometer is calibrated using a comparison method by using the reference accelerometer calibrated by the laser interferometer [13]. A mechanical coupler is a special type of force transducer with specifications of the mechanical impedance on its contact surface. The acceleration and force on the contact surface are measured to measure the mechanical impedance. Therefore, a calibrated accelerometer and mass are required to calibrate the impedance head [14]. The impedance head is used to calibrate the impedance of the mechanical coupler. The output force from

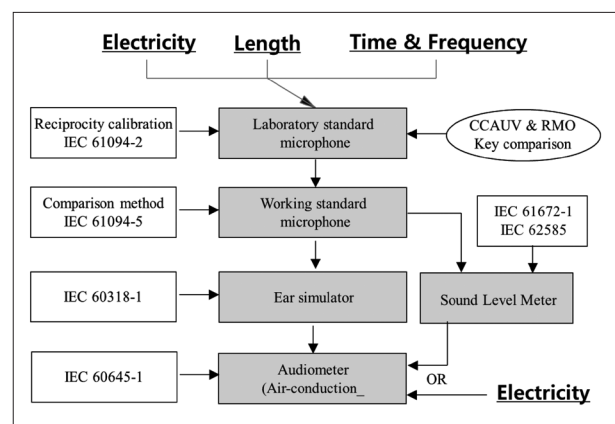


Fig. 1. Audiometer traceability chain (air-conduction response level).

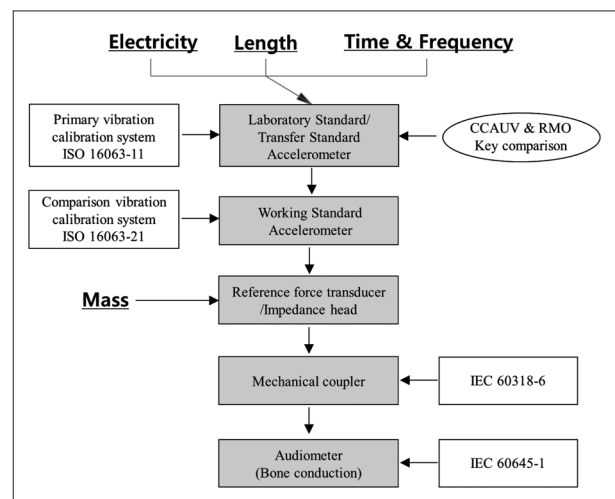


Fig. 2. Audiometer traceability chain (bone-conduction response level).

the mechanical coupler used to calibrate the bone-conduction stimuli of the audiometer. As shown in Figs. 1 and 2, the measurement instruments are connected to the primary stands by a chain of calibrations, which was the basis for trusting the measurement results.

Another essential aspect of the measurement is the uncertainty of the measurement, which is a parameter that characterizes the deviation associated with the measurement results. This parameter quantifies the reliability of the measurement results, which can be expressed quantitatively through an uncertainty evaluation at each calibration step using the primary standard [15].

Calibration of Ear Simulator

Calibration procedure of ear simulator for air-conduction transducers

The calibration procedure of the ear simulator, an air-coupled coupler having a specific structure, for the measurement of the supra-aural and circumaural earphones to determine the acoustic transfer impedance is described in IEC 60318-1: Annex C [4].

The configuration for measuring the acoustic transfer impedance was proposed in IEC 60318-1 [4]. Fig. 3 shows the conceptual configuration of the measurement system. Two pressure-type microphones (B&K Type 4192) are employed as the transmitter and receiver, and the acoustic responses between the two microphones is measured. For the transmitter capacitor, a transmitter unit (B&K ZE0796) with a nominal capacitance of 4.7 nF is employed. In addition, a function generator and a data acquisition system are required to generate the signal and measure the output voltage of each microphone channel, respectively.

The acoustic transfer impedance of this configuration is estimated by [4]

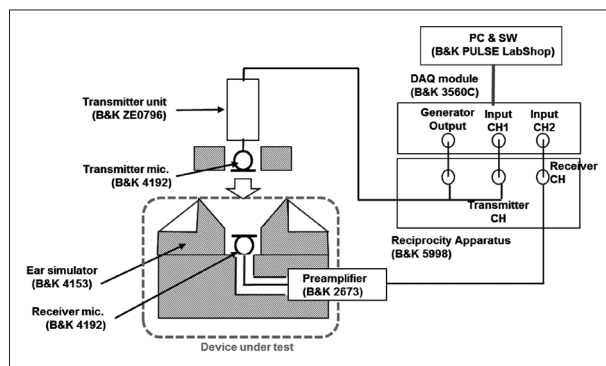


Fig. 3. Conceptual configuration of the measurement setup for calibrating the ear simulator by measuring the acoustic transfer impedance.

$$Z_a = \frac{1}{M_1 M_2} V_R \frac{1}{j\omega C}, \quad (1)$$

where M_1 and M_2 are the sensitivity of transmitter and receiver microphone, respectively, V_R is the voltage ratio between the transmitter microphone and receiver microphone, ω is the angular frequency, and C is the capacitance of capacitor connected to transmitter microphone.

Example of uncertainty evaluation of ear simulator for air-conduction transducers

Fig. 4 illustrates an example of the measured acoustic transfer impedance of the ear simulator B&K Type 4153, which was compared with the reference value. The measured transfer impedance was in the range of permissible deviation given by IEC 60318-1 [4]. However, measurement uncertainty must be considered to determine the reliability of the calibration results and to quantify their effect on hearing test results.

The combined standard uncertainty u_c is estimated by [15]

$$u_c^2 \cong \sum_{i=1}^N \left(\frac{\partial f}{\partial x_i} \right)^2 u^2(x_i). \quad (2)$$

Here, function f is given by Eq. (1), x_i is the i -th input quantity of the function, and $u(x_i)$ is the standard uncertainty associated with x_i . Each value in Eq. (1), contributes to the uncertainty in the acoustic transfer impedance.

Table 1 presents an example of the uncertainty budget for calibration of the ear simulator [16]. Here, the sensitivity of the microphones and capacitance were calibrated by following another standardized process. Usually, the value and its uncertainty in the calibration certificates are applied. The calibration uncertainty and resolution of the voltage-measurement device were included for the voltage-ratio measure-

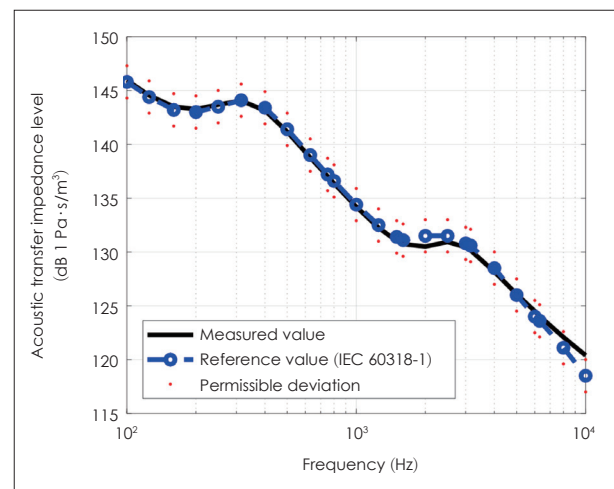
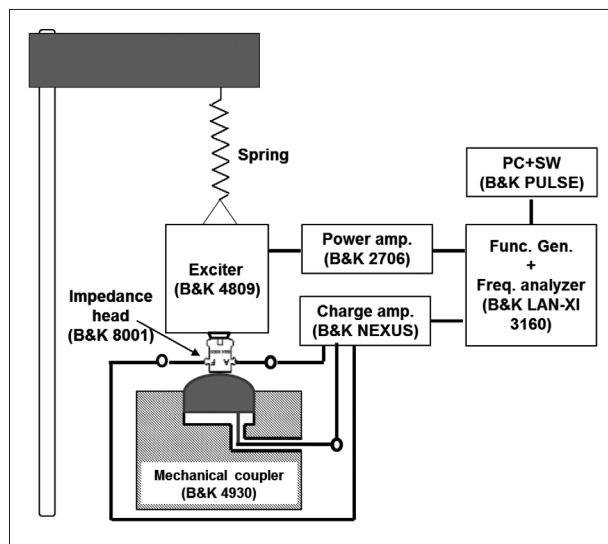


Fig. 4. Example of acoustic transfer impedance measurement results of ear simulator (B&K Type 4153).

Table 1. Example of the uncertainty budget for ear simulator calibration (air-conduction)

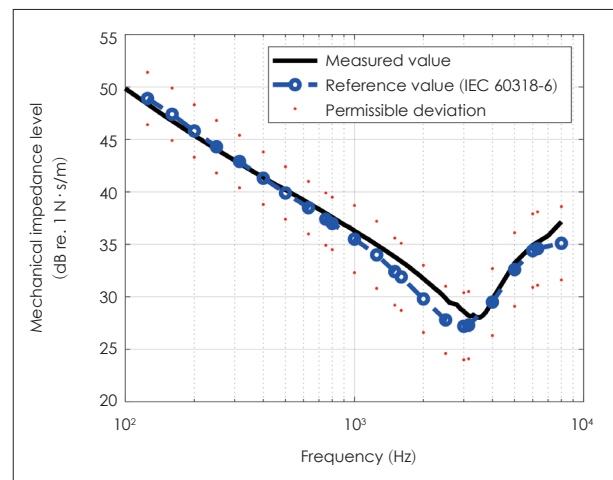
Standard uncertainty component	Cause of uncertainty	Uncertainty contribution (dB)						
		125 Hz	250 Hz	500 Hz	1 kHz	2 kHz	4 kHz	8 kHz
$u(M_1)$	Sensitivity of transmitter microphone	0.035	0.035	0.035	0.035	0.035	0.035	0.035
$u(M_2)$	Sensitivity of receiver microphone	0.035	0.035	0.035	0.035	0.035	0.035	0.035
$u(V_R)$	Voltage ratio measurement	0.091	0.101	0.046	0.036	0.027	0.022	0.025
$u(C)$	Capacitance	0.003	0.003	0.003	0.003	0.003	0.003	0.003
u_c	Combined standard uncertainty	0.11	0.11	0.067	0.061	0.057	0.054	0.055
$U(k=2)$	Expanded uncertainty for 95% coverage probability	0.22	0.22	0.14	0.13	0.12	0.11	0.11

**Fig. 5.** Conceptual configuration of the measurement setup for calibrating a mechanical coupler by measuring the mechanical impedance.

ment. Additionally, as the measurements performed in this procedure were voltage measurements, the effects of repeatability and reproducibility were included in this component. As shown in this example, the expanded uncertainty level, 95% degree of confidence was 0.11–0.22 dB, which was significantly smaller than the permissible deviation range stated in IEC 60318-1 [4]. Therefore, the calibration process and associated measurement systems are applicable for conformity assessments.

Calibration procedure of mechanical coupler for bone-conduction transducers

The output stimuli of bone conduction were calibrated using a mechanical coupler standardized in IEC 60318-6 [6]. Fig. 5 presents the conceptual configuration for calibrating the mechanical coupler by measuring the mechanical impedance. The exciter (B&K Type 4809) is in contact with the surface of the mechanical coupler to deliver vibrations through the impedance head (B&K Type 8001). The excitation system

**Fig. 6.** Example of mechanical impedance measurement results of the mechanical coupler (B&K Type 4930).

is suspended by a spring to contact the coupler with a certain static force which can be adjusted by adjusting the spring length. The measurements were conducted under two different static force conditions, 5.4 N and 2.5 N and the averaged value.

The mechanical impedance is estimated by [17]

$$Z_{\text{load}} = j\omega \left(\frac{F_{\text{imp,out}}}{a_{\text{imp,out}}} - m_{\text{platform}} \right), \quad (3)$$

where $F_{\text{imp,out}}$ is the force output of the impedance head, $a_{\text{imp,out}}$ is the acceleration output of the impedance head, and m_{platform} is the driving platform mass estimated from the ratio of force to acceleration without the constraint of the impedance transducer.

Example of uncertainty evaluation of mechanical coupler

Fig. 6 shows an example of the measured mechanical impedance of B&K Type 4930 compared to the reference value in IEC 60318-6 [6], and Table 2 presents an example of the uncertainty budget. The measured impedance was within the permissible deviation range, and the expanded measurement

uncertainty ranged from 0.8–2.0 dB. However, the calibration method for the sensitivities of the impedance head has not yet been standardized; therefore, it was calibrated following widely accepted previous research proposed by NMIs [14,17]. Force and acceleration were measured with and without loading (driving platform mass), and their uncertainties included the repeatability and resolution of the measurement.

These values are also sufficiently smaller than the allowable deviation range specified by IEC 60318-6 [6]. Therefore, the calibration process and associated measurement systems are applicable for conformity assessments.

Calibration of Audiometer Response Level

Audiometer calibration involves measuring the output of a transducer connected to an audiometer to quantitatively verify the difference by comparing it with the output levels specified in IEC 389-1 [18], IEC 389-3 [19], and IEC 60645-1 [3]. In the case of air-conduction stimulation, the sound pressure

level output through the simulated ear was measured. Meanwhile, the force level output through the mechanical coupler was measured for bone-conduction stimulation.

Calibration procedure and uncertainty—air conduction

Fig. 7 illustrates the conceptual configuration used to calibrate the air-conduction response. The transducer was placed on the ear simulator (IEC 60318-1 [4]) and pressed using a static force of $4.5 \text{ N} \pm 0.5 \text{ N}$. In this configuration, the source system (audiometer) and measuring system are separated. Thus, the system measures the sound pressure level using a coupler (ear simulator).

The air-conduction output response level of audiometer is estimated by

$$L_{\text{out}} = L_{\text{out,m}} - \Delta Z_{\text{ear}} = L_{\text{out,m}} - (Z_{\text{ear,nom}} - Z_{\text{ear,cal}}), \quad (4)$$

where $L_{\text{out,m}}$ is the measured sound pressure level (SPL) and $Z_{\text{ear,nom}}$ is the nominal impedance level (dB re. $\text{Pa} \cdot \text{s}/\text{m}^3$) of the ear simulator in IEC 60318-1 and $Z_{\text{ear,cal}}$ is the calibrated value

Table 2. Example of the uncertainty budget of the mechanical coupler

Standard uncertainty component	Cause of uncertainty	Uncertainty contribution (dB)						
		125 Hz	250 Hz	500 Hz	1 kHz	2 kHz	4 kHz	6 kHz
$u(M_a)$	Acceleration sensitivity of impedance head	0.10	0.10	0.10	0.10	0.10	0.10	0.10
$u(M_F)$	Force sensitivity of impedance head	0.10	0.10	0.10	0.10	0.10	0.10	0.10
$u(M_{\text{platform}})$	Driving platform mass	0.15	0.15	0.15	0.15	0.115	0.16	0.19
$u(Z)$	Measured ratio of force and acceleration with loading	0.55	0.33	0.33	0.33	0.40	0.40	0.90
u_c	Combined standard uncertainty	0.6	0.4	0.4	0.4	0.5	0.5	1.0
$U(k=2)$	Expanded uncertainty for 95% coverage probability	1.2	0.8	0.8	0.8	1.0	1.0	2.0

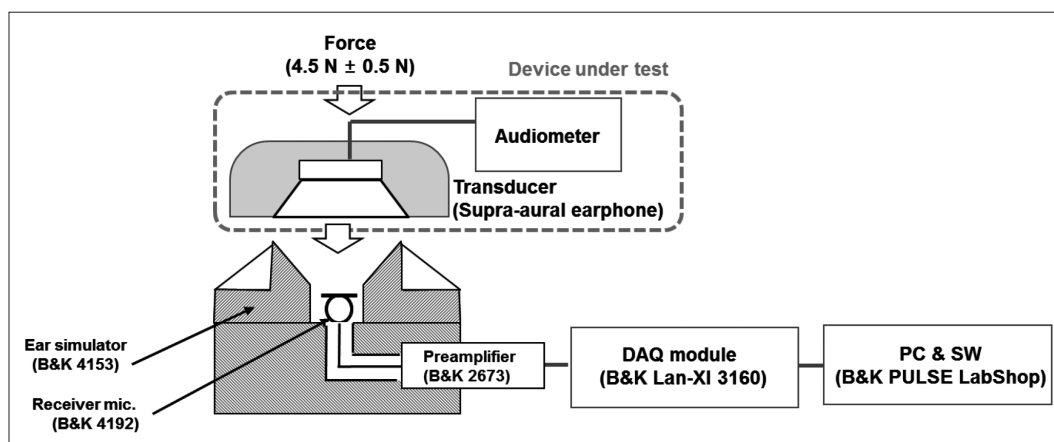


Fig. 7. Conceptual configuration of measurement setup for calibrating the air-conduction response level of audiometer.

of the impedance level. The measured SPL was expressed as follows:

$$L_{out,m} = L_E + M_{mic} + L_0, \quad (5)$$

where L_E is the measured voltage level, M_{mic} is the level of microphone sensitivity, and L_0 is the reference level of SPL given by 20 μ Pa.

Table 3 presents an example of the uncertainty budget for calibrating the air-conduction response level of an audiometer [20]. The component related to the voltage measurement is calculated using measurement uncertainty and standard deviation of the measured voltage. Uncertainty components related to the microphone include its calibration uncertainty and changes in environmental conditions [9,10]. The uncertainty of the ear simulator was estimated as described in the

previous section. When the range presented in the standard is adhered to the effect of static force is not significant [20]; however, the absence of leakage must be confirmed. Moreover, the reproducibility is related to the effect of placement of transducer on the ear simulator, which could be less than 0.2–0.5 dB if placed cautiously [20]. The expanded uncertainty of air-conduction response level of the audiometer is 0.5 dB up to 4 kHz and 1.1 dB for higher frequency. These values satisfy the uncertainty requirement and are sufficiently smaller than the allowable deviation of the audiometer requirement of IEC 60645-1 [3].

The IEC 60645-1 proposed a sound-level meter as an instrument to directly measure the sound pressure level throughout the coupler [3] which was calibrated using the method described in IEC 62585 [21]. The usual uncertainty level of sound level meter calibration is 0.2–0.3 dB which is slightly

Table 3. Example of uncertainty budget for calibration of the air-conduction response level of an audiometer

Standard uncertainty component	Cause of uncertainty	Uncertainty contribution (dB)										
		125 Hz	250 Hz	500 Hz	750 Hz	1 kHz	1.5 kHz	2 kHz	3 kHz	4 kHz	6 kHz	8 kHz
$u(L_E)$	Voltage	0.054	0.054	0.05	0.054	0.054	0.05	0.054	0.054	0.054	0.054	0.054
$u(L_{E,1})$	Frontend	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
$u(L_{E,2})$	Standard deviation	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
$u(M_{mic})$	Microphone sensitivity	0.075	0.075	0.08	0.075	0.075	0.08	0.075	0.075	0.075	0.075	0.075
$u(M_{mic,1})$	Calibration uncertainty	0.035	0.035	0.04	0.035	0.035	0.04	0.035	0.035	0.035	0.035	0.035
$u(M_{mic,2})$	Environmental condition	0.067	0.067	0.07	0.067	0.067	0.07	0.067	0.067	0.067	0.067	0.067
$u(Z_{ear,cal})$	Impedance of ear simulator	0.11	0.11	0.07	0.07	0.06	0.06	0.06	0.06	0.06	0.06	0.06
$u(\delta L_{static})$	Static force	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
$u(\delta L_p)$	Reproducibility	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.5	0.5
u_c	Combined uncertainty	0.25	0.25	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.51	0.51
$U(k=2)$	Expanded uncertainty	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	1.1	1.1

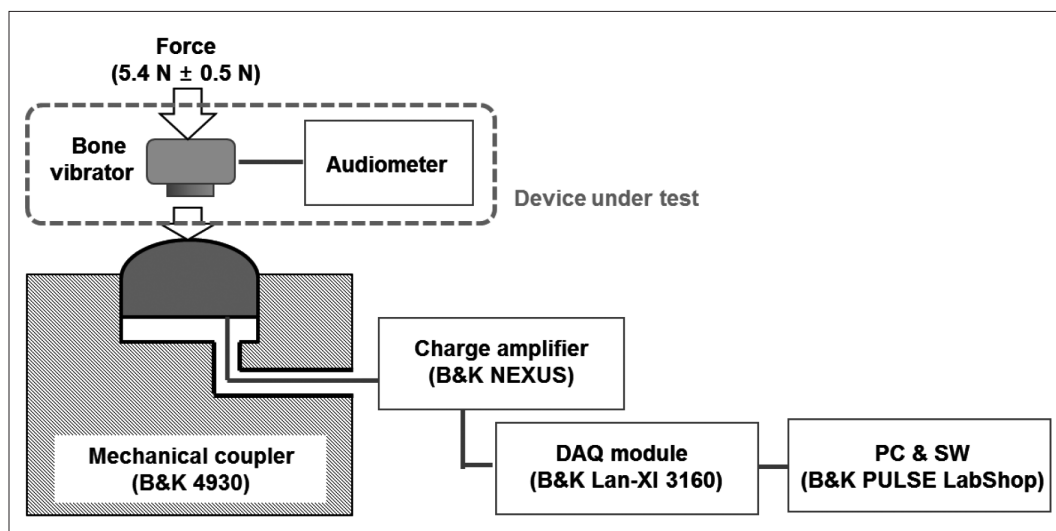


Fig. 8. Conceptual configuration of the measurement setup for calibrating the bone-conduction response level of the audiometer.

Table 4. Example of the uncertainty budget for calibration of the bone conduction response level of the audiometer

Std. unc. comp.	Cause of uncertainty	Uncertainty contribution (dB)								
		250 Hz	500 Hz	750 Hz	1 kHz	1.5 kHz	2 kHz	3 kHz	4 kHz	6 kHz
$U(L_E)$	Voltage	0.054	0.054	0.054	0.054	0.054	0.054	0.054	0.054	0.054
$U(L_{E1})$	Frontend	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
$U(L_{E2})$	Standard deviation	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
$U(Z_{ear,cal})$	Impedance of mechanical coupler	0.4	0.4	0.4	0.5	0.5	0.5	0.5	0.5	1
$U(\delta L_{static})$	Static force	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
$U(\delta L_{rp})$	Reproducibility	0.4	0.4	0.4	0.4	0.5	0.5	0.5	0.7	0.7
U_c	Combined uncertainty	0.64	0.64	0.64	0.71	0.77	0.77	0.77	1	1.3
$U(k=2)$	Expanded uncertainty	1.3	1.3	1.3	1.5	1.6	1.6	1.6	2	2.6

higher than the combined uncertainty of voltage measurement and the microphone. However, this increase did not significantly alter the total uncertainty and was acceptable for audiometer calibration.

Calibration procedure and uncertainty—bone conduction

Fig. 8 presents the conceptual configuration used to calibrate the air-conduction response. The transducer is placed on mechanical coupler according to IEC 60318-6 [6] and is pressed by static force of $5.4 \text{ N} \pm 0.5 \text{ N}$. Similar to air-conduction, the source system (audiometer) and the measuring system are separated.

A process similar to air conduction can be applied; an example of the uncertainty budget is presented in Table 4. The component related to voltage measurement was similar to that in the case of air conduction and the uncertainty of the mechanical coupler was estimated, as described in the previous section. However, the effect of the static force was much higher than that of air conduction [20]. Additionally, the uncertainty related to the reproducibility of the measurement is higher and related to changes in the contact conditions. The expanded uncertainty ranged 1.3–2.6 dB.

Discussion on Improving Reliability of Hearing Tests

The calibration procedure of the ear simulator for the measurement of the supra-aural and circumaural earphones is described in IEC 60318-1: Annex C. It requires an air-coupled coupler and a calibration procedure to determine the acoustic transfer impedance. Further, the output stimuli of the bone conduction is calibrated using a mechanical coupler standardized in ISO 60318-6. The traceable calibration process measures the output response level of an audiometer using these coupler devices. Additionally, we demonstrated the cal-

ibration process for each step and an evaluated the uncertainty of the results. Our results show that the traceability of each procedure can be secured to satisfy the uncertainty requirement and is sufficiently smaller than the permissible deviation of the audiometer requirement.

Uncertainty of hearing test

The cause of uncertainty contributing to the hearing test has been widely investigated. However, uncertainty reporting for actual calibration results of individual instruments is not currently conducted in most of audiometric devices. For this reason, since the uncertainty of the final hearing evaluation results is not able to estimated, there is no way to quantitatively explain how reliable the actual measurement results are.

An example of uncertainty evaluation in audiometry to determine the hearing threshold level is presented in ISO 8253-1: Annex A [1]. Threshold hearing level was estimated using the following equation [1]:

$$L_{TH} = L'_{TH} + \delta_{eq} + \delta_{tr} + \delta_n + \delta_{etc}, \quad (6)$$

where L'_{TH} is the outcome of the test procedure, δ_{eq} is the deviation induced by the audiometric equipment, δ_{tr} is the deviation of the transducer, δ_n is the deviation induced by the environmental conditions, and δ_{etc} is the uncertainty component induced by any other deviation due to the subjects and lack of the tester. δ is the deviation induced by practical conditions and should be zero in the ideal case.

In ISO 8253-1: Annex A, the uncertainty contribution is estimated for two main groups of uncertainty components: the quantities related to the equipment (δ_{eq} and δ_{tr}) and the subject (δ_{etc}). The components to the equipment imply that the uncertainty from the measurement of the equipment is estimated based on the allowable tolerance of each piece of the equipment. In the case of components related to the subject the estimation of the exact value requires a very sophisticated

ed statistical review. However, in this section, an approximate value is presented based on experience; for this reason, a relatively large value is assigned. As a result, the presented value in the example of IEC 8253-1 was 10–14 dB for air conduction and 11–15 dB for bone conduction. However, given that hearing test results are reported in 5 dB or 10 dB increments, this amount of uncertainty is considered quite large.

Considering these aspects, individual calibration of hearing test equipment is essential to ensure traceability of the equipment and improve the reliability of the final test results. Furthermore, research should be conducted to reduce the uncertainty related to individual differences in subjects and tester skills to obtain sufficiently effective values for the current hearing test resolution. This process also should be based on the quantified observation by the trusted measurement devices.

In this study, the psychosocial aspects are not considered and are limited to areas where objective evaluation is possible. However, the proposed approach provides a basis for clearer understanding of the causes of hearing assessment deviations in all fields.

Need for support in the field of metrology and consensus of user

The most fundamental problem of current standards system for audiometry is that the traceability of measurement standards is disconnected and the standard system is not strictly applied in medical field. As observed in this study and a previous study [22], the international standards related to hearing tests are advanced and well developed. However, in most countries, this is not subject to third-party certification, but is handled in the manufacturer's maintenance area, which is insufficient in comparison to quality management systems in other legal metrology areas. In principle, conformity assessment including calibration of legal metrology equipment requires third-party certification. In order to provide calibration services based on these measurement standards, the providing institute must also have a qualified quality system based on ISO/IEC 17025 [23]. However, most audiometric devices are currently not managed under this system, and reports specifying traceability and uncertainty are not provided.

Moreover, despite the developments of documentary standards, there are not enough resources in the metrology field to provide this. Currently, only three NMIs have registered calibration and measurement capabilities (CMC), which are the official measurement capabilities for audiometer calibration. The ear simulator has only five NMIs for air conduction and three for bone conduction. Therefore, the conformity test for hearing test devices does not operate in complete connection with the international measurement standard system.

While documentary standards have been well established in relation to hearing tests, there are several areas which lack sufficiently established and operated measurement standards. This can lead to passive adoption due to an insufficient understanding of the need for the establishment and management of measurement standards and because they are also directly related to cost and time. Additionally, as quality control appears to be implemented externally, no active issues are being raised. However, as mentioned earlier, this cannot be considered sufficient in comparison to other fields of legal metrology, and acts as a barrier that does not improve the accuracy and reliability of hearing evaluation. To overcome these problems, it is necessary to expand the understanding of quality infrastructure among stakeholders, identify the current status of high uncertainties and equipment deviations that actually occur, and form a consensus.

Conclusion

This study provides a brief review of the measurement standard system of audiometric devices and their calibration procedures and investigated the uncertainty of each calibration process and its effect on hearing test results.

Currently, the consideration of hearing test results based on measurement standards is not yet widely employed in the practical medical field. Therefore, it is difficult to conclude whether precise estimation and interpretation of test results based on this aspect are being carried out. Consequently, it is essential to calibrate the hearing test equipment individually and investigate it based on the concept of uncertainty to improve the reliability of hearing tests. Furthermore, research should be conducted to reduce the uncertainty related to individual differences in subjects and tester skills to obtain sufficiently effective values for the current hearing test resolution. To this end, close cooperation and mutual understanding between the metrology field and medical community are essential.

Conflicts of Interest

The authors have no financial conflicts of interest.

Author Contributions

Conceptualization: Kyung-Ho Park, Young Joon Seo. Investigation: Wan-Ho Cho. Methodology: Wan-Ho Cho, Jihyun Lee, In-Ki Jin. Project administration: Young Joon Seo. Wan-Ho Cho, Jihyun Lee. Supervision: Young Joon Seo. Writing—original draft: Wan-Ho Cho, Young Joon Seo. Writing—review & editing: Michelle J. Suh, In-Ki Jin, Tae Hoon Kong, Soo Hee Oh, Hyo-Jeong Lee, Seong Jun Choi, Dongchul Cha. Approval of the final manuscript: all authors.

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