



Understanding Standard Procedure in Auditory Brainstem Response: Importance of Normative Data

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The auditory brainstem response (ABR) is a noninvasive test that measures neural activity in response to auditory stimuli. Racial differences in head shape have provided strong evidence for specific normative data and accurate device calibration. International standards emphasize the need for standardized procedures and references. This study aimed to outline the standard procedure and related normative ABR values. Standard procedures were performed according to International Electrotechnical Commission (IEC) standards. Five studies from two countries were included to compare the normative values of the ABR. The dataset from the National Standard Reference Data Center (NSRDC) was used as reference. Normative values were described in terms of stimuli, latency, and amplitude. For click stimuli, the latency of the ABR showed different patterns across populations, such as those from Korea and the USA. Although the latencies reported by the NSRDC and for Koreans were relatively short, those reported for USA populations were longer. Using clicks, it was shown that the USA population had the largest ABR amplitude compared to those reported for the other two datasets. For Wave V latency using tone bursts, a similar pattern was identified with click stimuli. Frequency-specific trends were also observed. Although there is a lack of ABR datasets, the information and insights of the present study could be utilized as standard guidelines in research on ABR.

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Introduction

Auditory brainstem response (ABR) refers to the averaged

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response under scalp recording of neural activity occurred by acoustic signal and generated in the peripheral (i.e., auditory nerve) and central (brainstem) auditory system [1]. There are several synonyms such as brainstem auditory evoked response (BAER) or brainstem auditory evoked potential (BAEP), which is a diagnostic test that evaluates the electrical activity in the auditory nerve and brainstem in response to auditory

stimuli, typically clicks. It is a noninvasive test that involves placing electrodes on the scalp to detect the brain's response to sound. The ABR test is commonly used to assess hearing sensitivity, especially in individuals who may have had difficulty participating in traditional behavioral hearing tests, such as infants, young children, or individuals with developmental disabilities. The ABR provides information about the integrity of the auditory pathways from the ear to the brainstem and can help identify hearing loss, auditory nerve disorders, and neurological abnormalities affecting the auditory system.

During the 10 ms to 15 ms of time window after transient auditory stimulus, there are generally five positive peaks such as Wave I to V. An animal study using mice suggested the origin of each wave as follows: Wave I generated in the auditory nerve, Wave II derived from the cochlear nucleus, Wave III contributed from cochlea nucleus and superior olivary complex (SOC), Wave IV dominated by the vicinity of the periolivary and lateral lemniscal nuclei, and Wave V originated from the inferior colliculus [2]. In humans, Wave I originates from auditory nerve and represents the initial response of the auditory nerve fibers to auditory stimulation. Wave II arises from the cochlear nucleus and first relay level in the brainstem where auditory information is processed. Generally, Wave II has implication about synchronous firing of neurons in the cochlear nucleus. Wave III from the SOC is considered critical relay level in the brainstem such as integration of auditory inputs from both ears and binaural processing region. Wave IV is generated at the level of lateral lemniscus. Wave V, the final wave of the ABR measurement, occurs from the inferior colliculus in the midbrain [3,4].

As an electrophysiological test, the ABR provides objective hearing status of individuals regardless of age from infant to old adult. Because the ABR measurement records the detection of neural activity derived from the auditory stimulation, the detected thresholds of the ABR can be explained as the psychophysical thresholds [1]. In other words, the ABR measurement can be useful in the screening test and combination of behavioral measurement such as pure-tone audiometry (PTA) to confirm the reliability of the hearing tests. Contemporary researchers have revealed that the correlation between PTA and ABR was found at frequencies of 1 kHz to 4 kHz, with 2 kHz and 4 kHz being considered best frequencies to identify the hearing status [5-7]. To establish the reliability and accuracy of the results of hearing test, the normative data and concrete methods such as test parameters are inevitable. However, there are numerous possible factors that can introduce errors in measurement, including demographic factors (i.e., age, gender, history of noise exposure, and intake of ototoxic drugs), testing factors (i.e., types, length, intensity, polar-

ity, and trials of stimuli), and recording factors (i.e., epochs, filter settings, types of filters, time window, and number of sweeps). These challenges point out the importance of normative data and methodological approach in the ABR measurement.

The head shape and size differ among the race [8,9]. Head of Asians have rounder and flatter foreheads and backs than Caucasians [8]. This anthropometric characteristic between the race implicates the systematic normative data regarding the race is necessary [9]. There are several factors which impacted on the results of the ABR such as test environments, different pieces of equipment, and inaccurate output level of the ABR device itself [10]. Especially for the inaccurate output level of the device, calibration could be the powerful solution to obtain accurate responses and reliable interpretation. Calibration involves precise procedures to verify that the auditory stimuli are delivered at the correct intensity, polarity, and consistency [11]. Along with the calibration, standard reference and procedure are crucial to obtain reliable responses of the ABR and to provide accurate interpretation. Standard references refer to the benchmark or reference point, which is used for the purpose of calibration, comparison, and validation of measurements based on the accuracy and reliability [12].

International Electrotechnical Commission (IEC) 60645 series provided international standards related to the electroacoustics and audiometric equipment including PTA, impedance test, otoacoustic emissions, and ABR. Especially for the IEC 60645-7 entitled "Electroacoustics—Audiometric equipment—Part 7: Instrument for the measurement of auditory brainstem responses" addressed device specification for screening and diagnosis purpose [13]. For the stimuli and related variables, the IEC 60645-3 entitled "Electroacoustics—Audiometric equipment—Part 3: Test signals of short duration" described a sort of stimuli and/or electrical waveforms and methods of the measurement [14]. Contemporary researchers in different countries suggested normative data in terms of age, gender, and stimuli and recording variables, still it is unclear whether these data satisfied the standard procedure that IEC provided. The purpose of the current study was to outline the standard procedure and related normative value of the ABR. The mechanical specification of the ABR was also introduced to provide comprehensive understanding of measurement. For the last, we dealt with the standard procedures based on the International Organization for Standardization (ISO) standards. The information and insight of the present study could be utilized for standard guidelines in research with the ABR.

Materials and Methods

Standard stimuli and recording

Based on the IEC standard, a click is described as “transient acoustic or vibratory signal whose frequency spectrum covers a broad frequency range, produced by applying a single rectangular electrical pulse to the terminals of the transducer.” A tone burst, a sort of short duration, is defined as “sinusoidal signal having a duration of less than 200 ms.” Standard stimuli (i.e., click) of the ABR represent an electric rectangular pulse which single monophasic rectangular wave of $100 \pm 10 \mu\text{s}$ duration with rise and fall times less than $25 \mu\text{s}$ [14]. A tone burst is described as an electrical signal consisting of five periods of the fundamental sine wave with a linear rise and fall. The tone burst should contain 1.6 periods of rise and fall time, and duration of three periods [14].

Usually, sort of stimuli, including click and short tone burst, could be applied in the ABR test. Click was the most frequently used stimuli. There were several reasons to use the click: 1) highly synchronous neural activity which related to the clear and consistent waveforms of the ABR, 2) broad spectral range and short duration such as $100 \mu\text{s}$ were characterized to effective stimulating a wide area of the cochlea, especially the basal regions [7]. In other words, click stimuli produced maximal response activity from the high-frequency area of the cochlea and this activation led to a robust and clear waveform of the ABR, predominantly reflecting the activity from 2 kHz to 4 kHz region. These advantages made click stimuli useful in diagnosis of high-frequency hearing loss and highly correlated

with the hearing thresholds of the PTA.

However, click stimuli had relatively weak frequency-specific response in low frequencies such as 0.5 kHz and 1 kHz [15]. The frequency-specific response is derived from the narrow spectral energy centered around the primary frequency of the stimuli, which could be customized on the purpose of the ABR measurement [16]. Tone burst can provide precision in estimating auditory sensitivity at frequencies of 0.5 kHz to 4 kHz [16,17]. Several investigations suggested the clinical implication of the usage of tone burst for the alternatives of the click-evoked ABR in newborn and children [16,17].

Specification of device

Fig. 1 illustrates basic component of the ABR device consisted of 1) measurement system, 2) stimuli system, and 3) recording system. IEC standard explicated requirement of the ABR devices such as type of auditory signal (i.e., click), type of transducer and related headband force, sound field system, acoustic or vibratory signal levels for a given setting of the output level control, polarity of signal (i.e., positive, negative, alternating or random), repetition rate, duration of initial sound pressure of signal or vibratory force wave, rise/fall time of tone burst, and subjective relation of hearing level between test signals and the reference signal [14]. Equipment and method of calibration were also highlighted including type of ear simulator or mechanical coupler, method of coupling the transducer, and type of calibration (i.e., peak-to-peak equivalent sound pressure level or vibratory force level or in terms of hearing level).

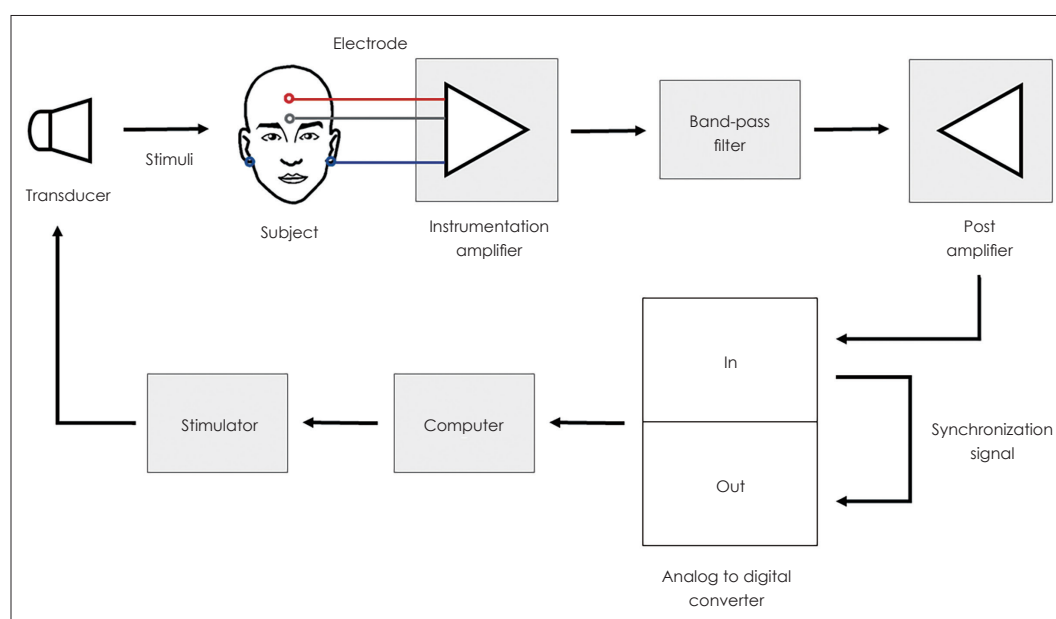


Fig. 1. Block diagram of the auditory brainstem responses device.

Especially for the Korea Standard (KS), detailed specifications of the ABR are divided into the types of devices such as type 1 (diagnostic/clinic) and type 2 (screening), as described in Table 1. For measurement system, measurement range between 2 μ V to 10 μ V and time resolution over 0.1 ms for type 1 device were included.

Along with the international standard, the National Standard Reference Data Center (NSRDC) was founded in Korea to establish the standard reference of Korea [18]. The NSRDC provided stimulus and recording variables based on the ISO/IEC/KS 60645-3 and -7 in Table 2.

Calibration of auditory brainstem responses

To acquire reliable and accurate results of the ABR measurement, calibration process was essential. IEC 60645-3 clearly stated that reference signals of the ABR, such as click and tone burst, to ensure the reference threshold levels in calibration process [14]. For earphone which most widely used in air conduction ABR measurement, the acoustic characteristics of the signals (i.e., click and tone burst) should be measured on an artificial ear [19] or occluded-ear simulator [20]. If the ABR measurement is conducted using bone conduction pathway, the bone vibrator is calibrated using reference signals. To calibrate bone vibrator, a mechanical coupler [21] should be placed to measure the peak-to-peak voltage of signal.

Article search and selection

To identify the normative data of the ABR across the country, articles were selected through systematic search process.

Three electronic journal databases—MEDLINE, PubMed, and Google Scholar—were used to search for articles. The key terms were “auditory brainstem response” AND “normal hearing” AND “normative data.” After search process, the articles were filtered with following inclusion criteria: 1) normal hearing subjects without otological history, 2) adults with age range of 19 to 29 to minimize the aging effect, 3) usage of standard stimuli such as click and tone burst, and 4) data acquisition of a series of waveforms under conditions similar to standard variables of ISO 60645-3 [14] and -7 [13]. Related variables of the ABR measurement including stimuli and recording are demonstrated in Table 3.

Normative data in domestic level

Domestic normative data were gathered through the NSRDC and two published articles by domestic researchers [22,23].

Table 2. Stimulus and recording variables on measurement of auditory brainstem response

Stimulus variable	Recording variable
Stimuli: Click	Amplification: 100,000
Repetition: 11 to 40 per second	Filter: (100–3,000) Hz for adults (10–3,000) Hz for infant
Polarity: Rarefaction	Notch filter: Out or In
Intensity: (10 to 90) dB nHL in 10 dB Step	Slopes: 6 dB nHL per octave
Duration: 100 μ s	Time window: (10–15) ms
Transducer: Insert phone	Number of sweeps: 1,000 to 2,000 Electrode array: Fz-Fpz-M1-M2

Table 1. Requirements of device specification

Description	Types of device	
	Type 1 (diagnosis/clinic)	Type 2 (screening)
Stimulus		
Stimulus fit with IEC [11]	O	O*
Stimulus level control (controllable stimulus level)	O	
Contralateral masking device	O†	
Signal processing		
Artifact reduction	O	O
Average controlled by user	O	
Detection of auto-response		O
Result display		
Display of test result	O	
Display of pass and refer		O
Display of quality measurement	O	
Documents		
Test results and parameter screen	O	
Save and export	O	

*explicated that manufacturer should be describe the other test stimulus; †explained that usually white noise used in contralateral masking. IEC, International Electrotechnical Commission

Table 3. Characteristics and main findings for reviewed studies for the country, participants, stimuli variable, recording variable, and main findings of each study

Study	Country	Participants	Stimuli variable	Recording variable	Main findings
The National Standard Reference Data Center [18]	Korea	32 normal hearing (female: 22, mean age: 22.95 yrs; male: 10, mean age: 22.7 yrs)	- Stimuli: click - Intensity: 10–90 dB nHL - Duration: 100 μs - Transducer: insert earphone - Polarity: rarefaction - Rate: 11–40 ms	- Amplification: 100,000 - Electrode array: Cz-to-A1, A2 - Filter setting: 100–3,000 Hz - Notch filter: out or in - Slope: 6 dB nHL per octave - Time window: 10–15 ms - Sweep: 1,000–2,000	The data from the National Standard Reference Data Center demonstrated that normative data as a function of age with systematic standard procedure.
Kim, et al. [22]	Korea	104 normal hearing (female: 53, mean age: 21.9 yrs; male: 51, mean age: 22.08 yrs)	- Stimuli: click - Intensity: 75 dB nHL - Duration: 100 μs - Transducer: ER-3A insert phone - Rate: 7.7 kHz	- Electrode array: Cz-to-A1, A2 - Filter setting: 100–3,000 Hz - Sweep: 2,048	The study found that female participants generally exhibited higher auditory brainstem response (ABR) amplitudes compared to male participants, regardless of noise conditions. Analysis of the data showed differences in ABR wave V latency between the two groups, with a mean latency of 5.87 ms for female participants and 5.61 ms for male participants. In terms of ABR wave V amplitudes, female participants had a mean amplitude of 0.47 mV, while male participants had a mean amplitude of 0.19 mV, indicating variations between the genders.
Burkard and Sims [24]	United States	Group 1: 11 young adults (female: 7, male: 4, mean age: 23.7 yrs), Group 2: 11 older adults (female: 7, male: 4, mean age: 69.3 yrs)	- Stimuli: click - Intensity: 115 dB nHL - Transducer: ER-3A insert phone - Polarity: alternating - Rate: 11, 25, 50, 75 Hz	- Electrode array: Cz-to-A1, A2 - Filter setting: 100–3,000 Hz - Sweep: 2,000	Older individuals showed longer latencies in their auditory brainstem responses compared to younger individuals, indicating age-related changes in auditory processing. The findings suggest that age is a significant factor in how the auditory system responds to high click rates, with older individuals exhibiting alterations in neural processing compared to younger individuals.
Lichtfuss [25]	United States	20 normal hearing (female: 10, male: 10)	- Stimuli: click - Intensity: 70, 80, 90 dB nHL - Transducer: ER-3A insert phone - Polarity: rarefaction - Rate: 19.1, 61.1 ms	- Electrode array: Cz-to-A1, A2 - Filter setting: 100–3,000 Hz - Sweep: 2,048	Various latency and amplitude measurements were taken to assess for retrocochlear pathology, with no significant differences found between the right and left ears in the participants. The results highlighted the importance of understanding ABR morphology and data replicability for clinical use, emphasizing the need for equipment-specific normative data for accurate assessments.

Table 3. Characteristics and main findings for reviewed studies for the country, participants, stimuli variable, recording variable, and main findings of each study (continued)

Study	Country	Participants	Stimuli variable	Recording variable	Main Findings
Chun and Han [23]	Korea	33 normal hearing (female: 19, male: 14, mean age: 23.4 yrs)	- Stimuli: tone burst - Intensity: 20, 30, 40, 50, 60, 70, 80 dB nHL - Transducer: ER-3A insert phone - Polarity: alternating - Rate: 40 ms	- Electrode array: Cz-to-A1, A2 - Filter setting: 100–3,000 Hz - Sweep: 1,500	Two Korean monosyllables (/ja/ and /cha/) and four frequencies of tone burst (500, 1,000, 2,000, and 4,000 Hz) were used to elicit the auditory brainstem response in 33 young adults with normal hearing. Results showed that the /ja/ syllable had a high correlation with 4,000 Hz tone burst, indicating similar results in the brainstem, while the /cha/ syllable correlated with 1,000 and 2,000 Hz tone burst, despite having different acoustical distributions. The findings suggest a disagreement between acoustic features and physiological outcomes at the auditory brainstem level.
Polonenko and Maddox [26]	United States	10 normal hearing (female: 5, male: 5, mean age: 22.6 yrs)	- Stimuli: tone burst (condition: 500, 1,000, 2,000, 4,000, 8,000 Hz) - Intensity: 25, 35, 45, 55, 65, 75 dB nHL - Transducer: ER-3A insert phone - Rate: 40 ms	- Electrode array: Cz-to-A1, A2 - Filter setting: 100–3,000 Hz	The parallel auditory brainstem response (pABR) method allows for faster accumulation of diagnostic information by simultaneously acquiring ABR waveforms, reducing the test duration significantly. The study show that the pABR yields high-quality waveforms over a range of intensities in adults with normal hearing, with similar morphology to the standard ABR but in a fraction of the recording time.

The NSRDC data included 64 ears from normal hearing subjects (mean age: 22.88 years, SD: 2.37). Among the included 64 ears, 44 ears were female. Dataset from Kim, et al. [22] included 208 ears (106 ears of females) from normal hearing subjects (mean age: 21.99 years, SD: 2.25). Only dataset from Chun and Han [23] adopted tone burst as stimuli. The dataset included 66 ears (38 ears of females) from normal hearing subjects (mean age: 23.40 years, SD: 1.50). All subjects of both the NSRDC and dataset from two published articles [22,23] had no otological disease, no history of noise exposure, medication usage at the time of experiments, and normal hearing thresholds (better than 15–25 dB HL across the test frequencies from 125 to 8,000 Hz).

To ensure the reliability and accuracy of the data, the NSRDC used standard ABR equipment, GSI Audera (Grason-Stadler, Eden Prairie, MN, USA), which was calibrated by Korean Research Institute of Standard and Science. Both studies [22,23] used standard equipment for evoked potential system such as Bio-logic Navigator Pro AEP (Natus, San Carlos, CA, USA).

Normative data in international level

International normative data was collected through only the USA [24–26]. The dataset from Burkard and Sims [24] included 22 ears (14 ears of female) from normal hearing subjects (mean age: 23.70 years, SD: 1.75). Dataset from Lichtfuss [25] consisted of 40 ears (20 ears of female) from normal hearing subjects (age range from 20 to 26 years). These studies used click as stimuli of the ABR measurement. Dataset from Polonenko and Maddox [26], which used tone burst as stimuli, included 20 ears (10 ears of female) from normal hearing subjects (mean age: 22.60 years, SD: 4.60). All subjects of dataset from three published articles [24–26] had no otological and/or neurological disease and normal hearing thresholds (better than 15–25 dB HL across the test frequencies from 250 to 8,000 Hz).

Various types of equipment were used in each study. The study of Burkard and Sims [24] used Nicolet Bravo system (Natus, San Carlos, CA, USA). Bio-logic Navigator Pro AEP (Natus, San Carlos, CA, USA) was adapted to study of Lichtfuss [25]. Only Polonenko and Maddox [26] used non-commercial AEP system which partially developed parallel ABR method.

Results

Normative data using click stimuli

The latency of the ABR measurement showed different pattern across the countries in Fig. 2. Although the differences were small, dataset of the NSRDC apparently showed the

lowest latency than the other two datasets from Korean studies and the USA. In detail, there were similar range of latencies between datasets in Wave I and III. However, the differences between countries were highlighted in Wave V. For latency of Wave I, the NSRDC showed 1.36 ms (SD: 0.08). However, the Korea (mean: 1.49 ms, SD: 0.14) and the USA (mean: 1.51 ms, SD: 0.02) showed prolonged latencies in Wave I. As the response of the ABR occurred in central auditory region, the gap of latency between countries was boosted. The latency of the NSRDC still showed shortest (mean: 3.56 ms, SD: 0.16), the USA (mean: 3.68 ms, SD: 0.14) and Korea (mean: 3.79 ms, SD: 0.15) were followed. Wave V showed similar latency with Wave I. The NSRDC showed 5.27 ms (SD: 0.23), and Korea (mean: 5.62 ms, SD: 0.25) and the USA (mean: 5.85 ms, SD: 0.35) were followed.

The amplitude of the ABR measurement showed different pattern across the countries in Fig. 3. Although the dataset of amplitude was not fully acquired, it is meaningful to identify the trends across the countries. Similar with the latency, amplitude showed that the USA had largest value than Korea and the NSRDC. The Korea showed 0.13 μ V (SD: 0.05) in Wave I. The NSRDC (mean: 0.23 μ V, SD: 0.09) and the USA (mean: 0.52 μ V, SD: 0.29) were followed. For wave III, considering the absence of dataset from the USA, Korea showed 0.21 μ V (SD: 0.06) amplitude which is smaller than the NSRDC (mean: 0.28 μ V, SD: 0.13). In wave V, Korea showed smallest value of amplitude (mean: 0.19 μ V, SD: 0.08), and the NSRDC (mean: 0.21 μ V, SD: 0.14) and the USA (mean: 0.31 μ V, SD: 0.16) were followed. These results demonstrated that there were clear and consistent pattern in the ABR results across the countries.

Normative data using tone burst stimuli

Two dataset from Korea and the USA with latency of the

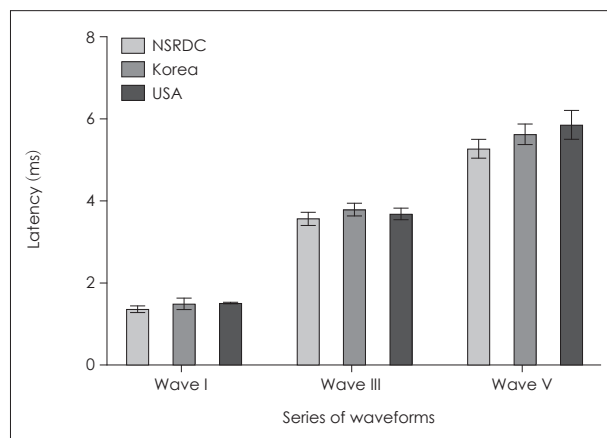


Fig. 2. Latency of auditory brainstem response using click stimuli for a series of waveforms across the countries.

ABR were used in the normative data using tone burst stimuli (Fig. 4). Even though the frequency-specific characteristics were identified, overall pattern was similar with the click stimuli. That is, normative latency data from the USA showed a prolonged duration compared to Korea. For tone burst of 500 Hz, latency of Korea dataset showed 8.04 ms (SD: 0.17) and the USA showed 12.91 ms (SD: 0.3). Korea dataset showed 7.99 ms (SD: 0.1), 7.61 ms (SD: 0.07), and 7.26 ms (SD: 0.01) for frequencies of 1,000 to 4,000 Hz. The USA showed 10.15 ms (SD: 0.31), 8.04 ms (SD: 0.3), and 7.05 ms (SD: 0.35) for 1,000, 2,000, and 4,000 Hz, respectively. Interestingly, latency of each country had different trends in terms of test frequency. That is, as the frequency of tone burst increased, the latency of the USA was shortened. Unlike the USA, dataset from Korea showed consistent latency range, regardless of the frequency of tone burst.

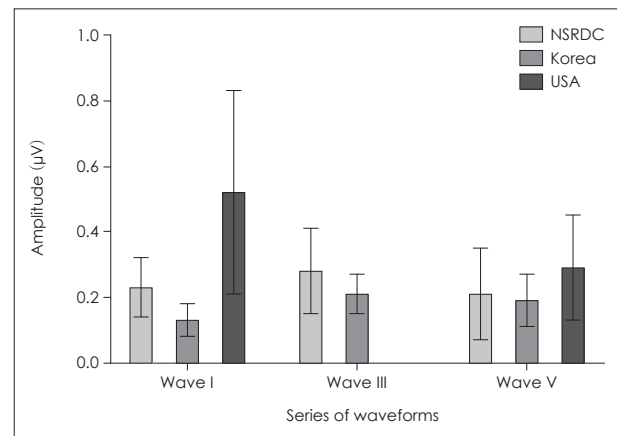


Fig. 3. Amplitude of auditory brainstem response using click stimuli for a series of waveforms across the countries.

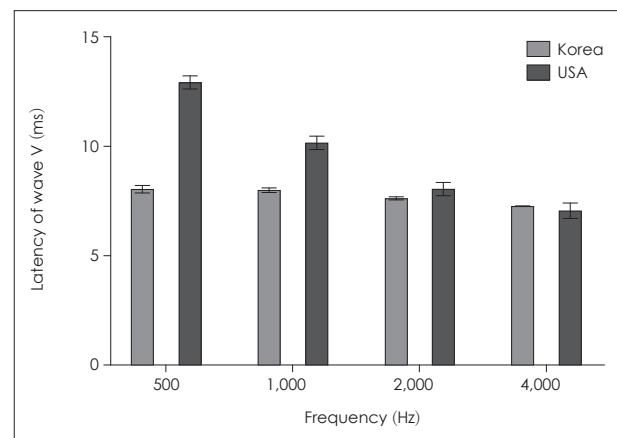


Fig. 4. Latency of auditory brainstem response using tone burst stimuli for a series of frequencies across the countries.

Discussion

This paper described the structured outline of standard procedure and normative data of the ABR from domestic to international level. Standard procedure and device specifications were provided based on the NSRDC and the IEC standards.

IEC 60645-7 covers instruments used to measure evoked potentials from the inner ear, auditory nerve, and brainstem in response to short-duration acoustic and/or vibratory stimuli. It specified the required characteristics and performance standards for both screening and diagnostic instruments to ensure consistent measurements across various compliant devices. IEC 60645-7 boosted innovation and did not include the use of electric stimuli for specialized applications [13].

The normative data of ABR in domestic level included the NSRDC and Korean research groups. As the reference standard of the ABR measurement, the NSRDC highlighted standard procedure of data collection. The NSRDC collected reference data of hearing such as hearing thresholds of PTA and amplitude and latency of ABR as a function of age. Moreover, dataset from Korean [22,23] and the USA [24-26] research groups was utilized in the current study to identify country-specific normative data in the ABR.

Although we gathered normative datasets from systematic article search and selection process, there were lack of study samples and variables such as absence of amplitude to enrich the comparison across the countries. There were several studies from different countries (i.e., China, Denmark, India, and Iran) that were entered in article search process, but they did not fulfill our inclusion criteria to minimize the heterogeneity of dataset. Thus, the current study focused on the general distribution and country-specific characteristics of the ABR variables such as latency and amplitude in indirect manner.

The results of the current study demonstrated that there were clear pattern and characteristics of the ABR measurement across the countries. Using click stimuli, latency of the ABR showed higher values in the USA than datasets from Korea and the NSRDC. Latency of the ABR itself gradually increased (prolonged) as the responded region of auditory pathway more centrally, the degree of prolonged gap was different among the counties. The anthropometric characteristics of Caucasians (USA) and Asians (Korea) could lead to the degree of gap in latency [8,9]. There were significant morphological differences between the head shapes of Asian and Caucasian populations. With round head and flatter back and forehead, several factors may affect to the ABR measurement such as placement of electrode and sound transmission. According to Trune, et al. [27], there was a significant correlation between size of head and outcomes of the ABR mea-

surement such as amplitude and latency. There were several correlated extrinsic factors (i.e., head diameter, gender, and age) on the outcomes of the ABR measure, and two factors including head diameter and gender were highly correlated with both latency and amplitude of the ABR. In other words, if the size of head increased, the latency was prolonged and the amplitude was decreased. These findings implicated population-specific ABR measurement procedure and necessity of normative data.

This paper described the structured outline of standard procedure and normative data of the ABR from domestic to international level. Standard procedure and device specification were provided based on the NSRDC and the IEC standard.

The hearing thresholds from the PTA, which is a representative hearing test, had international standard dataset, called ISO 7029 [28]. ISO 7029 entitled "Acoustics—Statistical distribution of hearing thresholds related to age and gender" provided descriptive statistics of hearing thresholds in terms of age and gender. In addition, there was attempt to update the hearing thresholds as a function of age [29]. Unfortunately, the ABR related variables were not set into international standard dataset and only the related procedures were presented such as test signals of short duration [14] and instrument for the measurement of auditory brainstem responses [13]. Many contemporary researchers conducted and published articles based on their own research questions, and the dataset consisted of patients with hearing loss in most cases. Although the datasets in the published articles had a clear purpose and could be utilized in clinical application, heterogeneity of datasets was inevitable and necessity of normative data of the ABR with international standard procedure was emphasized [17].

Conflicts of Interest

The authors have no financial conflicts of interest.

Author Contributions

Conceptualization: all authors. Data curation: Chanbeom Kwak, Yuseon Byun. Formal analysis: Wan-Ho Cho, Tae Hoon Kong, Soo Hee Oh. Investigation: Sunghwa You, Young Joon Seo, Hyo-Jeong Lee, Michelle J. Seo. Methodology: Chanbeom Kwak, Yuseon Byun, Junghee Sagong, Young Joon Seo. Project administration: Soo Hee Oh, Seong Jun Choi, Dongchul Cha. Resources: Young Joon Seo, Chanbeom Kwak, Wan-Ho Cho. Software: In-Ki Jin, Michelle J. Suh. Supervision: Kyung-Ho Park. Validation: Hyo-Jeong Lee, Seong Jun Choi, Dongchul Cha. Writing—original draft: Chanbeom Kwak, Young Joon Seo. Writing—review & editing: all authors. Approval of final manuscript: all authors.

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