Standardization of calibration scheme in NB Chirp ABR Hearing Assessment: A Preliminary Study Based on Normal Hearing Soldiers

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Research

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Abstract

Background: Optimal medical intervention for veterans suffering from military noise-induced hearing impairment is a major concern of the specialists in military medicine, otology, and audiology sectors. Thus, it is important to objectively and accurately reflect the hearing level of the subject in the intervention to aid hearing and improve the existing hearing disability evaluation program.

Purpose: The present study intends to identify the optimal correction scheme by comparing the accuracy and range of deviation of narrow-band chirps evoked auditory brainstem responses (NB Chirp ABR) corrected by different schemes in estimating the hearing level of people with normal hearing.

Methods: A total of 66 individuals could hear sounds of a frequency <25dB hearing level (HL) in the pure tone audiometry were randomly divided into a model group (26 subjects), test group 1 (with 20 subjects), and test group 2 (with 20 subjects). The mean threshold difference and the regression equation at each frequency were obtained through the model group, and the correction results of the “mean threshold difference scheme (S1)” and the “regression equation scheme (S2)” were compared in the test groups 1 and 2. All data were analyzed using SPSS 24.0.

Results: 1) The accuracy of the estimated hearing level (eHL) of non-corrected NB Chirp ABR was significantly higher than that of NB Chirp ABR corrected by S1 or S2; 2) The range of deviation of the eHL of non-corrected NB Chirp ABR from the pure tone audiometry threshold was greater than that of NB Chirp ABR corrected by S1 or S2 from the pure tone audiometry threshold at 500 and 1000 Hz, while at 2000 and 4000 Hz, the values were similar.

Conclusion: Among people with normal hearing, it was necessary to correct NB Chirp ABR at 500 and 1000 Hz for higher accuracy of the eHL, but the strengths of different correction schemes were not defined. For clinical convenience, the “mean threshold difference scheme,” with the correction values of 7 and 4 dB, was recommended for correction. At 2000 and 4000 Hz, it was not necessary to correct NB Chirp ABR. Thus, additional subjects with different HLs should be included in future studies to discuss the differences between the two schemes.

1. Research Background

Hearing is essential for human beings to participate in social interaction[1] (Palmer et al., 2019) and is a key factor that determines life quality[2, 3]. Strikingly, many servicemen in multiple branches of the military, including high artillery, artillery, armoured troops, naval forces, air force pilots and ritual artillery are suffering hearing impairment of different degrees due to long-term exposure to military noises [4, 5], which affects their life. The formulation, introduction, and enforcement of the *Veterans Support Law of the People’s Republic of China* has improved the policies to protect the rights and interests of veterans, and how to provide medical intervention for veterans suffering military noise-induced hearing impairment is a major concern of military medicine, otology, and audiology specialists.

For military servicemen with permanent hearing impairment, hearing aids, cochlear implants, and other auditory aids can help them have normal or nearly normal hearing, thereby improving their life quality. However, an effective hearing aid requires accurate evaluation of the patient's existing hearing level (HL). The pure tone audiometry is deemed as the "golden standard" of hearing evaluation but is easily affected by the subjective willingness or disposing capacity as it requires the active cooperation (subjective willingness) of the subject. Therefore, a test to objectively and accurately reflect the hearing level of the subject is crucial in the intervention to aid hearing and also help to improve the exit from hearing disability evaluation program.

The frequency specified auditory brainstem response (fsABR) test, requiring no active cooperation of the subject and being significantly correlated with the thresholds at all frequencies of the behavioral audiometry (including the pure tone audiometry), has been widely used in the objective evaluation of hearing at different frequencies [6, 7]. However, the fsABR threshold is an electrophysiological threshold and cannot reflect the real hearing level of the subject, and hence, it can only be used to calculate the estimated value of the pure tone audiometry, i.e., the dB estimated hearing level (dB eHL), after correction [8]. The accuracy of the eHL affects the evaluation of the subjects by clinicians or audiologists, as well as the determination of the hearing intervention scheme, which eventually, affects the intervention effect in patients with hearing impairment. A high eHL enhances the effect of the hearing aid, while low eHL results in a smaller gain; both phenomena affect the hearing and speech ability of patients with hearing impairment and aggravate hearing impairment [9, 10, 11]. Thus, how to accurately estimate the pure tone audiometry threshold with the fsABR threshold has always been a focus in the studies on clinical audiology.

Chirp is a novel ABR stimulus signal that gives low-frequency signals and then high-frequency signals in one stimulus cycle according to the physiological characteristics of the cochlea, targeting the sound signals at different frequencies to the corresponding regions in the cochlear basement membrane to activate the auditory nerve fibers and record the ABR signals [12] (Cebulla and Elberling, 2010). The narrowband Chirp (NB Chirp), a frequency-specific (mid-frequency) sound stimulus signal obtained by limiting the frequency bandwidth based on Chirp, is applied to fsABR increasingly. Some studies demonstrated that NB Chirp ABR causes a better neural response than tone burst ABR (TB-ABR) [13, 14, 15, 16] and is preferred for fsABR, but the results of studies on the correction value for TB-ABR cannot be applied to NB Chirp ABR due to the differences in the physical properties of the sound signal and the induced neural response between NB Chirp ABR and TB-ABR. Thus, it is necessary to correct NB Chirp ABR using other correction values.

The existing schemes commonly used to correct ABR are as follows. In Scheme 1 (S1), the ABR and pure tone audiometry thresholds are obtained from a group of subjects with normal hearing, the mean difference (i.e., the correction factor) between the two thresholds is calculated, and the eHL is calculated by deducting the correction factor from the clinically obtained ABR threshold [17]. In Scheme 2 (S2), the subjects with different HLs are included. Subsequently, the linear regression equation between the ABR threshold and the pure tone audiometry threshold is fitted, and the corresponding eHL is obtained by inputting the clinically obtained ABR threshold into the equation [18]. The strength of S1 is that it is easy to operate as the corresponding correction factor can be obtained by a clinical hearing test center based on the test results of subjects with normal hearing, and the weakness is that it ignores the effects of the degree of hearing impairment on the difference between the thresholds [19, 20], resulting in over-estimation or under-estimation of the HL of a subject. The strength of S2 is that it takes into account the effects of different degrees of hearing impairment on the difference between the thresholds, and can estimate the HL accurately, while the weakness is that the fitting of the equation is affected by the quantity and quality of test data and is complicated to operate in the clinical practice. Which of the S1 and S2 is suitable for correcting the eHL of NB Chirp ABR?.

The current study compared the eHL of NB Chirp ABR corrected by the two schemes, respectively, with the pure tone audiometry threshold and observed a significant difference in the accuracy of the eHL between the two correction schemes (S1 and S2), in order to provide a reference for a standardized objective hearing evaluation with NB Chirp ABR in clinical practice.

Soldiers with normal hearing were included in this study as subjects in order to avoid interference with the study results by auditory nerve dysfunction and provide baseline data for future studies on patients with different degrees of hearing impairment.

This study was part of a research registered at the Chinese Clinical Trial Registry on February 29, 2020 (ChiCTR2000030337, http://www.chictr.org.cn/showproj.aspx?proj=49367) .

2. Subject And Methods

2.1 Research subjects

Soldiers with normal hearing were recruited from the First Medical Center of Chinese PLA General Hospital as subjects of the study.

Inclusion criteria: 1) A person without hearing loss, tinnitus, vertigo, or other ear symptoms in daily life; 2) A person with smooth external auditory canals and undamaged tympanic membrane and without cerumen impaction or middle ear inflammation or fluid; 3) A person without a history of noise exposure; 4) A person who voluntarily participates in the study.

Exclusion criteria: 1) A person whose acoustic reflex of the stapedius failed to be elicited at any frequency, ipsilaterally and/or contralaterally; 2) A person with any octave frequency threshold >25 dB HL at 125–8000 Hz in the pure tone audiometry; 3) A person who failed to complete a stimulus signal test at any frequency.

A total of 66 soldiers, average age 26.61±7.90-years-old, were included in this study.

2.2 Research methods

All tests in this study were carried out at the Clinical Hearing Test Center of the First Medical Center, Chinese PLA General Hospital. The ambient noise in the soundproof chamber and the electromagnetically shielded chamber was ≤26 dB (A). The pure tone audiometer and the auditory evoked potentiometer were tested and calibrated by the Testing and Research Station of Medical Acoustics Measurement of the PLA.

Before the official start of the test, the external auditory canal and the tympanic membrane were observed under the electric otoscope, and GSI TympStar II middle ear analyzer was used to perform acoustic immittance to exclude the volunteers whose acoustic reflex of the stapedius failed to be elicited. Then, two audiologists, blinded to the test results, performed the pure tone audiometry and the NB Chirp ABR test separately (a subject did not undergo the NB Chirp ABR test if he/she had an abnormal result in the pure tone audiometry).

All data were independently and statistically analyzed by one statistician. The included volunteers were randomly grouped into the model group (26 males, average age 26.77±7.21-years-old), the test group 1 (20 males, average age 25.00±7.58-years-old), and the test group 2 (20 males, average age 28.00±9.11-years-old).

2.2.1 Pure tone audiometry

The pure tone audiometry was performed with the Astera pure tone audiometer (Otometrics, Denmark) in a soundproof chamber according to the national standards. Before test, each volunteer was informed about the operating procedures of the test with respect to air conduction and bone conduction thresholds according to *Acoustics - Audiometric Test Methods - Part 1: Pure-tone Air and Bone Conduction Audiometry* (GB/T 16296.1-2018) at test frequencies of 125 Hz, 250 Hz, 500 Hz, 1000 Hz, 2000 Hz, 4000 Hz, and 8000Hz (not 125 Hz and 8000 Hz in the bone conduction audiometry). The minimum sound intensity at a reliable response of >50% could be obtained at each frequency and was defined as the threshold of the frequency.

2.2.2 NB Chirp ABR test

The NB Chirp ABR test was performed with the Eclipse auditory potentiometer (Interacoustics, Denmark) in an electromagnetically shielded chamber. Before the test, each subject was placed in a supine position. The skin was degreased at the forehead hairline, between eyebrows, and at both ear lobes with 95% ethanol. The skin cutin was removed at the same positions with abrasive paper. After skin cleansing, a button-shaped recording electrode was placed at the forehead hairline, a button-shaped ground electrode was placed between the eyebrows, and two button-shaped reference electrodes were placed at both ear lobes. The resistance between the electrodes was ≤1kΩ. Each subject was required to close eyes and remain calm and quiet during the test. Plug-in earphones (ER-3A) were used in the test for stimulus signals of alternating waves at a stimulation rate of 20.1 Hz and bandpass filter of 33–1500 Hz, which were repeated 2000 times. The test started with 80 dB nHL and took the V wave as the observation indicator of the threshold. It proceeded by gradually lowering the hearing level at a step of 10 dB nHL until the V wave was not readable; at this point, the hearing level was increased by 5 dB nHL. Then, with the step of 5 dB nHL, the V wave was searched for the repeatable minimum intensity, which was indicated as the NB Chirp ABR threshold. The stimulus signals included 500, 1000, 2000, and 4000 Hz NB-Chirp.

2.2.3 Schemes to correct the NB Chirp ABR threshold

S1 and S2 were used in this study to correct the eHL of NB Chirp ABR. In S1, the eHL was calculated by adding up the mean difference (correction factor) between the NB Chirp ABR threshold and the pure tone audiometry threshold. In S2, the eHL was calculated by substituting the NB Chirp ABR threshold into the regression equation between the NB Chirp ABR threshold and the pure tone audiometry threshold.

2.2.4 Standards to judge the accuracy of the eHL

The threshold of non-corrected NB Chirp ABR, the eHL of NB Chirp ABR, NB Chirp ABR corrected by S1, and the eHL of NB Chirp ABR corrected by S2 were compared to the pure tone audiometry threshold. A threshold difference <1 dB (inclusive) indicated "conformity," a threshold difference <5 dB (inclusive) indicated "fair conformity," and a threshold difference >5 dB indicated "inconformity." The absolute value was used in this study to judge the accuracy of the eHL as either positive bias (where the eHL is higher than the behavioral audiometry threshold) or negative bias (where the eHL is lower than the behavioral audiometry threshold) that would interfere with the clinical scheme.

2.3 Statistical analysis

SPSS 24.0 was used for data organization and analysis. Descriptive data were expressed as mean±standard deviation. The correlation analysis was used to study the correlation between the pure tone audiometry threshold and the NB Chirp ABR threshold at the same frequency, as well as the eHL, and the rank-sum test was applied to compare the correction effects of the two schemes. $P<0.05$ indicated statistical significance.

3. Results

3.1 Correlation analysis between the NB Chirp ABR threshold and the pure tone audiometry threshold

The correlation analysis (Table 1) showed that the NB Chirp ABR threshold was significantly correlated with the pure tone audiometry threshold at 500, 1000, 2000, and 4000 Hz frequency in the model group (n=52 ears). Specifically, the highest correlation coefficient was at 4000 Hz, a lower correlation coefficient was at 2000Hz, and the lowest correlation coefficient was at 1000 Hz.

Insert Table 1 approximately here

3.2 Correction factors for the eHL of NB Chirp ABR

The NB Chirp ABR threshold and the pure tone audiometry threshold of the model group (n=52 ears) at 500, 1000, 2000, and 4000 Hz frequency was compared, and the threshold differences were 6.54±8.32

dB, 4.33±6.72 dB, 2.02±4.47 dB, and 1.35±6.03 dB, respectively. The rounding off of the mean values of the threshold differences provided the correction factors, 7, 4, 2, and 1 dB, at the corresponding frequencies.

3.3 Regression equation model for the eHL of NB Chirp ABR

The monadic regressive analysis of the NB Chirp ABR threshold and the pure tone audiometry threshold in the model group (n=52 ears) at 500, 1000, 2000, and 4000 Hz frequency was utilized to establish the following regressive estimation models:

1) Estimated pure tone threshold at 500 Hz = 5.66 + 0.38 × NB-Chirp ABR threshold at 500 Hz

2) Estimated pure tone threshold at 1000Hz = 6.31 + 0.34 × NB-Chirp ABR threshold at 1000 Hz

3) Estimated pure tone threshold at 2,000Hz = -0.77 + 0.92 × NB-Chirp ABR threshold at 2000 Hz

4) Estimated pure tone threshold at 4,000Hz = -1.09 + 0.98 × NB-Chirp ABR threshold at 4000 Hz

3.4 Correlation analysis between eHLs of the two correction schemes and the pure tone audiometry threshold

Data of the test group 1 (n=40 ears) and the test group 2 (n=40 ears) were processed based on the correction factors and regression equation obtained from the model group, and the corresponding eHL was obtained. The correlation analysis showed that the eHLs of the two groups were significantly correlated with the pure tone audiometry threshold at 2000 and 4000 Hz (P<0.01), while at 500 Hz, only the eHL of the test group 2 was significantly correlated with the pure tone audiometry threshold ($p_{test\ group\ 1}$=0.06, $p_{test\ group\ 2}$=0.004), and at 1000 Hz, only the estimated hearing level of the test group 1 was significantly correlated with the pure tone audiometry threshold ($p_{test\ group\ 1}$=0.03, $p_{test\ group\ 2}$=0.11).

3.5 Comparison of accuracy of eHLs between two correction schemes

The rank-sum test showed that the eHL of non-corrected NB Chirp ABR was significantly accurate than that of NB Chirp ABR corrected by S1 and S2 (Figure 1).

In the test group 1, at 500 Hz, the accuracy of the eHL of non-corrected NB Chirp ABR was significantly different from that of NB Chirp ABR corrected by S1 and that of NB Chirp ABR corrected by S2 (P<0.001, P=0.01), while that of NB Chirp ABR corrected by S1 differed little from that corrected by S2 (P=0.16). At 1000 Hz, the accuracy of the estimated hearing level of the non-corrected NB Chirp ABR was significantly different from that corrected by S1 and that corrected by both S1 and S2 (P=0.01, P=0.01), but differed slightly from that corrected by S2 (P=0.48). At 2000 Hz frequency, the accuracy of the estimated hearing level of non-corrected NB Chirp ABR was significantly different from that of NB Chirp ABR corrected by S1 and that of NB Chirp ABR corrected by S2 (P<0.001, P<0.001), while that corrected by S1 differed only slightly from that corrected by S2 (P=1.000). At 4000 Hz, the accuracy of the eHL of the non-corrected NB

Chirp ABR differed little from that corrected by S1 (P=0.82), while that of the non-corrected NB Chirp ABR and that of NB Chirp ABR corrected by S1 were significantly different from that corrected by S2 (P<0.001, P<0.001).

In the test group 2, at 500 Hz, the accuracy of the estimated hearing level of the non-corrected NB Chirp ABR differed little from that of the NB Chirp ABR corrected by S2 (P=0.09), while that of the non-corrected NB Chirp ABR and that of NB Chirp ABR corrected by S2 both significantly differed from that corrected by S1 (P<0.001, P=0.04). At 1000 Hz, the accuracy of the eHL of non-corrected NB Chirp ABR differed little from that corrected by S1 (P=0.16) but was significantly different from that corrected by S2 (P=0.01), while that corrected by S1 differed little from that corrected by S2 (P=0.50). At 2000 Hz, the accuracy of the eHL of non-corrected NB Chirp ABR was significantly different from that corrected by S1 and S2 (P<0.001, P<0.001), while that corrected by S1 differed little from that corrected by S2 (P=0.60). At 4000 Hz, the accuracy of the estimated hearing level of non-corrected NB Chirp ABR differed little from that corrected by S1 (P=0.82), while that of the non-corrected NB Chirp ABR and that of NB Chirp ABR corrected by S1 were significantly different from that corrected by S2 (P<0.001, P<0.001).

3.6 Comparison of the range of the threshold difference between the two correction schemes

The bubble map of the threshold differences of the two correction schemes (Figure 2) showed that the range of deviation of the eHL of non-corrected NB Chirp ABR from the pure tone audiometry threshold was greater than that of S1 and S2 at 500 and 1000 Hz, while they were similar at 2000 and 4000 Hz.

In the test group 1, one-sample t-test was performed on the differences between the thresholds of non-corrected NB Chirp ABR, NB Chirp ABR corrected by S1, and NB Chirp ABR corrected by S2. Consequently, the threshold differences at 500 and 1000 Hz of non-corrected NB Chirp ABR were significantly different from “0” (P<0.001, P<0.001) but same at 2000 and 4000 Hz (P=0.10, P=0.20). The threshold differences at all frequencies of NB Chirp ABR corrected by S1 and S2 differed little from “0” (P=0.10, P=0.40, P=0.81, P=0.62, P=0.21, P=0.92, P=0.96, P=0.83). Paired-sample t-test was performed on the differences between the thresholds of NB Chirp ABR corrected by S1 and S2, and no significant between-group differences were detected at 500 and 1000 Hz (P=0.22, P=0.09), while significant between-group differences were noted at 2000 and 4000 Hz (P=0.01, P=0.00).

In the test group 2, one-sample t-test was performed on the differences between thresholds of non-corrected NB Chirp ABR, NB Chirp ABR corrected by S1, and NB Chirp ABR corrected by S2. Threshold differences at 500 and 1000 Hz of non-corrected NB Chirp ABR were significantly different from “0” (P<0.001, P<0.001) while the same at 2000 and 4000 Hz differed little from “0” (P=0.05, P=0.25), and the threshold differences at all frequencies of NB Chirp ABR corrected by S1 and S2 differed little from “0” (P=0.11, P=0.79, P=0.90, P=0.75, P=0.20, P=0.74, P=0.97, and P=0.98). Paired-sample t-test was performed on the differences between the thresholds of NB Chirp ABR corrected by S1 and S2, and no significant between-group differences were observed at 500, 1000, and 2000 Hz (P=0.48, P=0.41, P=0.41), while the significant between-group difference was observed at 4000 Hz (P<0.001).

4. Discussion

fsABR is a frequency-specific technique to objectively evaluate the hearing level recommended by exiting guidelines. In order to improve the accuracy of fsABR in individual hearing evaluation, new stimulus signals, stimulus parameters, and correction schemes are currently being sought. NB Chirp signal is a new stimulus signal applied to fsABR. In clinical practice, the neural signals induced by NB Chirp signals are better quality than existing frequency-specific stimulus signals (tone burst signals) and are preferred in many applications. The current study demonstrated that among the subjects with normal hearing, the NB Chirp ABR threshold was significantly correlated with the pure tone audiometry threshold, suggesting that the former could reflect the latter, which proved the superiority of NB Chirp signals in judging the threshold. Although this phenomenon has been discussed in many clinical studies from the perspective of testing technique, testing subjects, and clinical characteristics, NB Chirp ABR threshold is only an electrophysiological value and can only be used to evaluate individual HLs after correcting effectively. Only a few studies are available on the schemes to correct NB Chirp ABR. Consequently, the study compared the two existing correction schemes, the mean threshold difference scheme and the regression equation scheme, in people with normal hearing, to assess the differences in the accuracy and range of deviation of the estimated hearing level, in order to provide data support for the standardized clinical application of NB Chirp ABR.

In the mean threshold difference scheme, it was assumed that the difference between the NB Chirp ABR threshold and the pure tone audiometry threshold conformed to the normal distribution to ensure that the mean threshold difference could meet the correction demand of the majority of the individuals in all subjects. In the regression equation scheme, a stable correlation was assumed between the NB Chirp ABR and the pure tone audiometry. Consequently, the result of t pure tone audiometry could be estimated according to the results of objective tests. Thus, the threshold of the corrected NB Chirp ABR should be closer to the threshold of the pure tone audiometry. The study also demonstrated conformity when tested by non-corrected NB Chirp ABR and the pure tone audiometry. The possible reasons were as follows: 1) The NB Chirp acoustic stimulus differentiated the ABR wave, which made it easier for detectors to observe and judge the NB Chirp ABR threshold closer to the pure tone audiometry threshold; 2) Either correction scheme required large sample size, while our study was conducted on small sample size, making it difficult to prevent sampling deviation from affecting the accuracy of correction schemes and further affecting the correction results. Therefore, future studies will be based on the data of the study with an adequate number of samples.

Notably, although many subjects had the conformity result in the threshold of non-corrected NB Chirp ABR, the bubble map showed that the maximum absolute deviation was between 15 and 20 dB at 500z and 1000 Hz when NB Chirp ABR was not corrected, suggesting a higher risk of error to be borne by subjects, while the absolute deviation of NB Chirp ABR corrected by S1 and S2 was <0 dB, suggesting a lower risk of error. Thus, the NB Chirp ABR threshold at 500 and 1000 Hz need to be corrected to minimize the risk of error in clinical results. Due to similar hearing levels of the subjects in the current study, it was impossible to define whether S1 or S2 was preferred for the existing data. However, for clinical convenience, S1 (the mean threshold difference scheme) was recommended for correction with 7 dB and 4 dB values. It was unnecessary to correct NB Chirp ABR at 2000 and 4000 Hz as these had a similar range of deviation and several subjects had the conformity result at 2000 and 4000 when NB Chirp ABR was not corrected.

5. Conclusion

The present study recommended the correction scheme in the clinical practice of NB Chirp ABR, but did not guarantee that such a correction scheme could be applied to people with different HLs as only a limited number of subjects with normal hearing were included in the study. People with different HLs will be included in future studies to validate and improve the scheme to correct NB Chirp ABR.

6. Declarations

6.1 Ethical Approval and Consent to participate

The study was approved by the Ethics Committee of the First Medical Center of Chinese PLA General Hospital (S2020-168-01). All subjects signed informed consent before the experiment.

6.2 Consent for publication

All authors have read and approved the content, and agree to submit for consideration for publication in the journal.

6.3 Availability of data and materials

The datasets generated and/or analyzed during the current study are not publicly available due to the individual privacy, but are available from the corresponding author on reasonable request.

6.4 Competing interests

There are no any ethical/legal conflicts involved in the article.

6.5 Funding

This study was not funded.

6.6 Authors' contributions

Li Zhicheng, Lai Xiaofen and Lai Jinmei were in charge of the audiology test of the volunteers; Li Zhicheng wrote the manuscript; Qi Min summarized all the audiology examination data of the volunteers; Yuan Lianxiong was responsible for the statistical analysis of the research data; Zeng Xiangli and Ji Fei planned the structure and examined the content of the manuscript, and perfected the manuscript.

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Tables

Table 1 Correlation analysis between the NB Chirp ABR threshold and the pure tone audiometry threshold

	500 Hz PTA	1000 Hz PTA	2000 Hz PTA	4000 Hz PTA
500 Hz NB Chirp	r=0.56 P<0.001**			
1000 Hz NB Chirp		r=0.31 P=0.02*		
2000 Hz NB Chirp			r=0.63 P<0.001**	
4000 Hz NB Chirp				r=0.92 P<0.001**

Figures

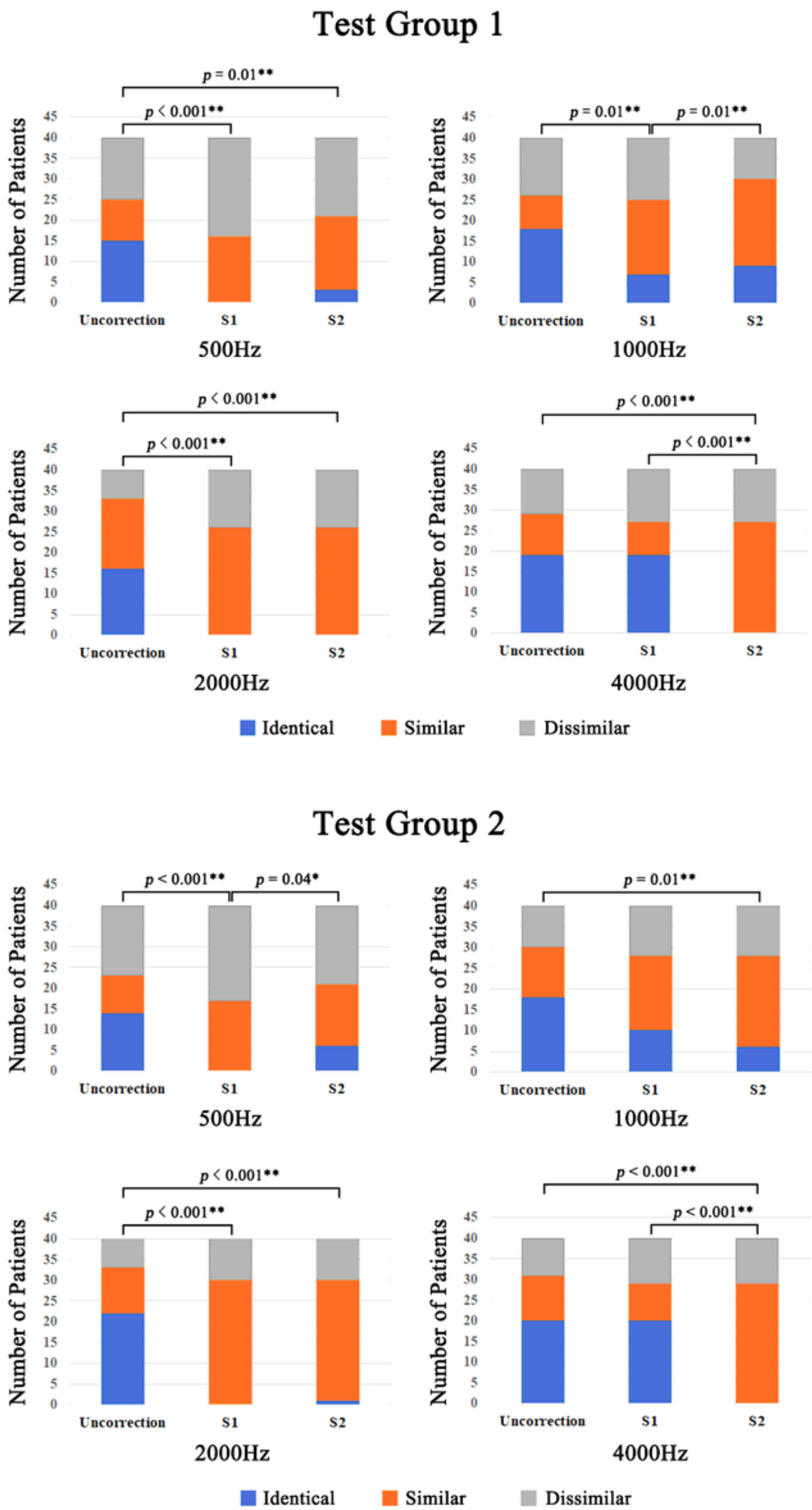

Figure 1

Comparison of the accuracy between two correction schemes

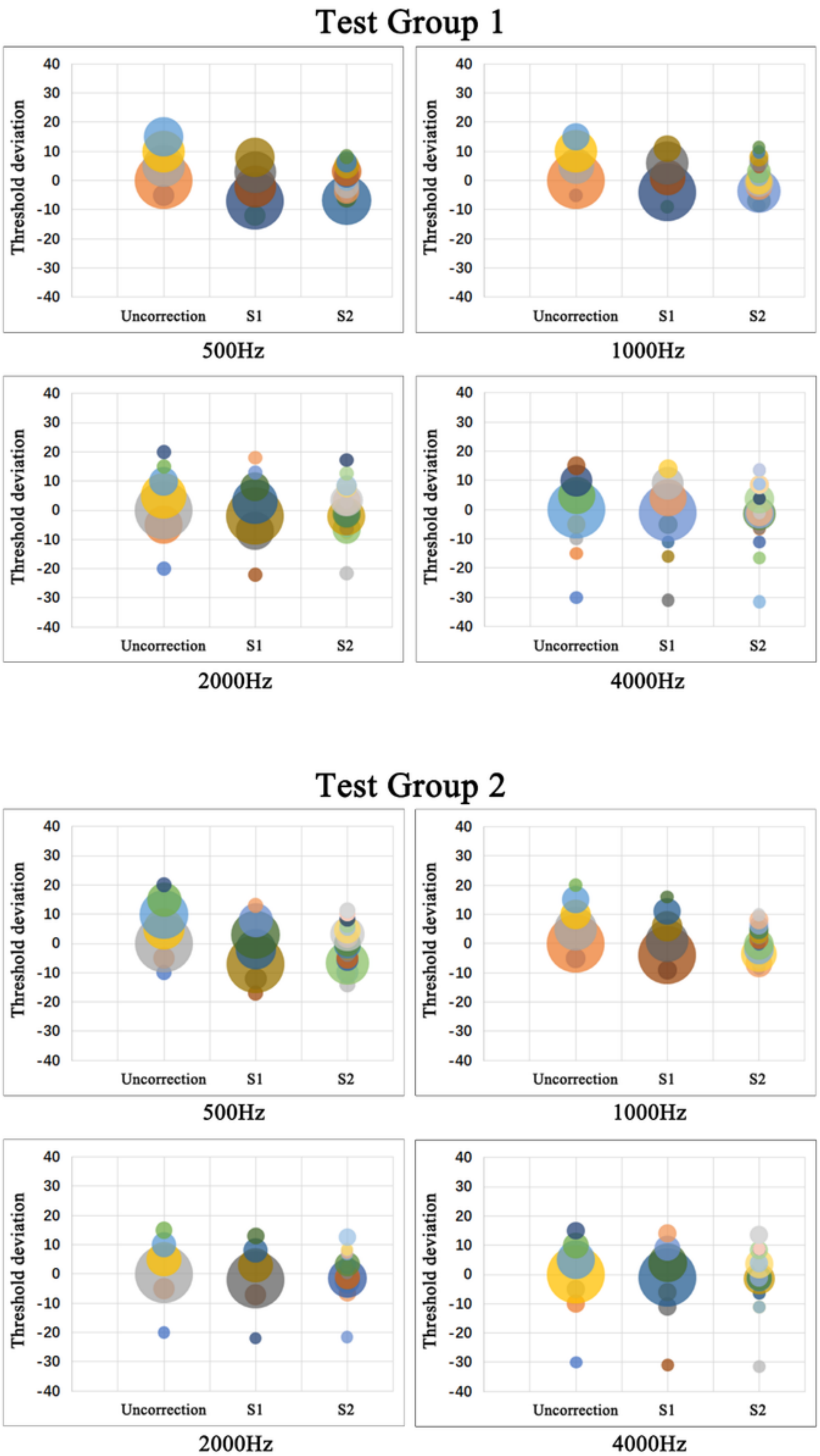

Figure 2

Comparison of the range of threshold difference between two correction schemes