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Comparative study of objective hearing thresholds in adults using Auditory Steady State Response and Auditory Brainstem Response with Pure Tone Audiometry

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Abstract

Background: Pure-tone audiometry (PTA) is the most common audiological test to determine hearing thresholds. However, accurate assessment of hearing in difficult-to-test populations has always remained an audiological challenge as it gives inconsistent responses in PTA.

Aim: This study aimed to evaluate the reliability of the Auditory Steady State Response (ASSR) and Auditory Brainstem Response (ABR) in determining the frequency-specific hearing thresholds by establishing a correlation between the thresholds determined by subjective test- PTA and objective test - ASSR and ABR at 500 Hz, 1 kHz, 2 kHz and 4 kHz.

Methods: In this prospective study we have included 40 adult subjects (n = 80 ears) of both genders. All subjects underwent ASSR, tone burst ABR and PTA to record frequency-specific hearing thresholds at 500 Hz, 1 kHz, 2 kHz and 4 kHz. Data were recorded and analyzed with SPSS IBM software version 22.

Results: The mean difference between PTA - ASSR was 14.2 dB and between PTA - ABR was 18.8 dB in the study population. We found a strong correlation between PTA-ASSR and PTA-ABR across all frequencies. We also confirmed that correlation was better in the sensorineural hearing loss and conductive hearing loss group in comparison with the normal hearing group. The overall reliability was better in high frequency for both ASSR and ABR.

Conclusion: Results of this study concluded that both ABR and ASSR can be used to predict frequency-specific hearing thresholds. ASSR was more reliable than ABR for accurate prediction of frequency-specific hearing threshold as the mean difference between ASSR and PTA was smaller than the mean difference between ABR and PTA.

Conflicts of Interest: The Authors declare no conflicts of interest.
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Introduction

Hearing plays a crucial role in language and intellectual development. Pure tone audiometry (PTA) is the gold standard for hearing evaluation, but it is difficult to perform conventional pure tone audiometry in difficult to test populations. This can occur when a person is inattentive or uncooperative or has a limited understanding of test instructions. In these situations, objective audiometry becomes an essential tool to know the hearing level of person. At least one in a thousand newborns is affected by permanent hearing loss (1-4). Obtaining precise and objective hearing information for a child is crucial for early intervention and maximizing the development of receptive and expressive language abilities (5,6). Due to the objective nature of the test, auditory brainstem response was introduced in

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screening children for hearing loss worldwide (7-9). Many times, patients may exaggerate hearing loss while claiming compensation. Studies show, 9–30% of workers magnify their hearing loss (10-12). Hence there is always a need for objective audiometry. Auditory steady-state response (ASSR) and auditory brainstem response (ABR) are two objective tests of hearing evaluation.

The ABR is an auditory evoked potential that is recorded via electrodes placed on the scalp and identifies the abnormalities in the integrity of central auditory pathways. ASSR is also an auditory evoked potential that is elicited by a tone that fluctuates periodically over time. It is an electrophysiological response to quick auditory stimuli and generates a statistically valid audiogram (13,14).

ASSR and ABR also have important differences. ABR is generated using brief sounds presented at a low repetition rate, whereas ASSR is generated using repeated sound stimuli presented at a high repetition rate. In ABR, amplitude and latency detection are done in the temporal domain whereas in ASSR, amplitudes and phases are detected in the spectral (frequency) domain. In ASSR multiple frequencies, and both ears can be tested together whereas in ABR single frequency and one ear can be tested at a time.

The aim of this study was to compare two objective methods of hearing, ASSR and ABR, with PTA in determining the frequency specific hearing thresholds and also to identify which is the better method. We also examined effects of types of hearing loss on them.

This study is different from previous studies as most of previous studies have been done on paediatric population, however, we have done it on the adult population. Secondly most of the previous studies compared either of the objective tests with PTA, however, we have compared both the objective tests with PTA simultaneously.

Methods

This was a prospective study which was conducted at a tertiary hospital of the Armed Forces after approval of the Institutional Ethical Committee with reference number: CHAFB/1911/12/IEC. Informed consent was obtained from each patient.

The study was comprised of 40 subjects (n=80 ears) aged 21 to 77 years (Mean age 41.12 years), who visited the department of ENT with or without complaints of decreased hearing. Those patients who cannot give a valid response in PTA or patients with active ear disease or with congenital ear malformation are excluded from this study. PTA was performed in all the subjects and depending on their hearing acuity they were divided into three groups. Group 1 consisted of 43 ears of sensorineural hearing loss (SNHL)), group 2 consisted of 15 ears with conductive hearing loss (CHL) and 22 ears of normal hearing (NH) were placed in group 3. ASSR and ABR were performed on all these individuals. Normal hearing (n=22) was defined as an air conduction and bone conduction threshold of 25 dB or less, SNHL (n= 43) was defined as air conduction and bone conduction threshold of more than 25 dB and CHL (n= 15) was defined as an air conduction threshold > 25 dB with bone conduction threshold < 25 dB. All the tests were done on the same day in each individual in a sound proof room. PTA was performed by clinical audiometer model 2001 digital (Arphi) calibrated according to the standards of American National Standards Institute S3.6–1996. Air conduction and bone conduction thresholds were obtained at frequencies of 500 Hz, 1 kHz, 2 kHz, and 4kHz, respectively. ABR and ASSR were performed using Neurosoft version 1.14 (Neurosoft, Ivanovo, Russia). The electrodes were applied on the scalp as both tests are far-field auditory evoked potential tests. Each ear was tested for frequencies of 0.5, 1, 2, and 4 kHz, respectively using ER-3A insert earphones in both tests.

In ASSR, the four carrier frequencies 500 Hz, 1kHz, 2kHz, and 4 kHz were tested

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simultaneously in both ears. 100% amplitude modulation and 20% frequency modulation were used for all carrier frequencies, with the response confidence set at 95% as predetermined by the system manufacturer. The: modulation rates were 84, 88, 92, and 96 Hz for the right and 86, 90, 94, and 98 Hz for the left ear, for 500 Hz, 1kHZ, 2kHz, and 4 kHz carrier frequencies, respectively. A gain of 200 k, a low-pass filter at 105Hz and a high-pass filter at 65Hz were used. The ASSR software analyses the consistency of response and determines whether the sound is heard or not, utilizing an algorithm that uses a fourier linear combiner with an adaptive filter and circular statistical analysis.

The measurements of ASSR were performed using a descending procedure, by recording electrical responses while reducing the intensity of the acoustic signal in 10 dB steps until the threshold. The threshold was defined as the minimum intensity of detected responses, with a maximum of 5 min search time for each frequency allowed. The average recording time for ASSR was 30 mins in each person. Tone burst stimuli were used for ABR in four frequencies 500 Hz, 1kHz, 2kHz, and 4 kHz separately. Tone bursts were applied linearly, gated with one cycle plateau and two cycles rise and fall times. The tone bursts were presented at a repetition rate of 33.3Hz with rarefaction polarity and the total number of sweeps presented were 2000. The time window was taken as 20 milliseconds. The test was started at 90 dB HL and lowered down to 10 dBHL. A 10 dB decrement was used to determine the threshold. The threshold was determined at the lowest level at which wave V was identified in the waveform. The average recording time of ABR was 45 mins for each person.

Statistical methods

PTA was considered the primary outcome variable. ASSR and ABR were considered explanatory variables. Descriptive analysis was carried out by mean and standard deviation. The association was assessed by calculating the Pearson correlation coefficient (r) and the data was represented in a scatter diagram. The reliability between the two methods was evaluated by calculating the intra-class correlation coefficient (ICC). The method chosen for ICC assessment was a two-way mixed effects method with a single rate measurement. P value < 0.01 was considered statistically significant and IBM SPSS version 22 was used for statistical analysis.

Results

A total of 80 ears were included in the final analysis. Among them, 43 ears had SNHL, 22 ears had normal hearing and the remaining 15 ears had CHL (Table 1). The mean age was 41.12 years with the minimum age being 21 years and the maximum age was 77 years in the study population. Of these, 55% were male and 45% were female.

Table 1: Descriptive analysis of groups in the study population (N=80)

Groups	Frequency	Percentages
SNHL	43	53.75%
Normal	22	27.50%
CHL	15	18.75%

Table 2 shows the mean PTA, mean ASSR and mean ABR thresholds level in the SNHL group (n=43).

Similarly, Table 3 shows the mean PTA, mean ASSR and mean ABR thresholds level in the CHL group (n=15) and table 4 shows the mean PTA, mean ASSR and mean ABR thresholds level in the NH group (n=22).

In the SNHL group, there was a moderate positive correlation between PTA and ASSR at frequencies 500 Hz and 4000 Hz with r values 0.594 and 0.682, respectively and a strong

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positive correlation at 1000 Hz and 2000 Hz with r values 0.783 and 0.817, respectively.

Table 2. Descriptive analysis of PTA and ASSR & ABR in SNHL group (n=43)

Frequency	Mean PTA	SD	Mean ASSR	SD	Mean BERA	SD
500 Hz	37.79	16.05	57.33	19.77	61.63	16.32
1 kHZ	40.58	16.98	59.65	17.16	65.12	17.37
2 kHz	48.60	16.84	61.16	19.72	65.81	17.76
4 kHZ	62.79	16.95	76.16	17.31	79.77	13.88

Table 3. Descriptive analysis of PTA and ASSR & ABR in CHL group (n=15)

Frequency	Mean PTA	SD	Mean ASSR	SD	Mean BERA	SD
500 Hz	38.33	20.24	51	18.63	52.67	21.20
1 kHZ	38.33	17.18	51	17.85	54	21.65
2 kHz	35.67	12.94	45.33	12.88	55.33	15.98
4 kHZ	40	19.18	50.67	19.54	56.67	17.99

Table 4. Descriptive analysis of PTA and ASSR & ABR in NH group (n=22)

Frequency	Mean PTA	SD	Mean ASSR	SD	Mean BERA	SD
500 Hz	17.50	7.52	30.45	12.23	34.09	7.96
1 kHZ	18.18	6.08	32.04	12.60	35	8.02
2 kHz	17.27	5.50	28.41	7.77	33.64	7.27
4 kHZ	19.32	9.91	32.27	14.61	36.82	12.87

There was a moderate positive correlation between PTA and ABR at frequency 4000 Hz with r value of 0.691 and a strong positive correlation at 500 Hz, 1000 Hz and 2000 Hz with r values 0.746, 0.732 and 0.879, respectively (p-value: <0.001) (Table 5).

Table 5. Correlation between PTA and ASSR & PTA and ABR among SNHL group (N=43)

	Pearson rank correlation (r)	P value
ASSR (Hz)		
500	0.594	<0.001
1000	0.783	<0.001
2000	0.817	<0.001
4000	0.682	<0.001
ABR (Hz)		
500	0.746	<0.001
1000	0.732	<0.001
2000	0.879	<0.001
4000	0.691	<0.001

Among the CHL group, there was a strong positive correlation between PTA and ASSR at frequencies 500 Hz, 1000 Hz and 4000 Hz with r values 0.914, 0.722 and 0.893, respectively and a moderate positive correlation at 2000 Hz with r value 0.613. There was a strong positive correlation between PTA and ABR across all frequencies with r values 0.910, 0.730, 0.776 and 0.869 at 500 Hz, 1000 Hz, 2000 Hz and 4000 Hz, respectively. (Table 6).

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Table 6. Correlation between PTA and ASSR & PTA and ABR among CHL group (N=15)

	Pearson rank correlation (r)	P value
ASSR (Hz)		
500	0.914	<0.001
1000	0.722	0.002
2000	0.613	0.012
4000	0.893	<0.001
ABR (Hz)		
500	0.910	<0.001
1000	0.730	0.002
2000	0.776	0.001
4000	0.869	<0.001

Among the normal hearing group, there was a moderate positive correlation between PTA and ASSR at frequencies 1000 Hz and 2000 Hz with r values 0.563 and 0.506, respectively and a strong positive correlation at 500 Hz and 4000 Hz with r values 0.776 and 0.824, respectively.

There was a weak positive correlation between PTA and ABR at frequencies 5000 Hz, 1000 Hz and 2000 Hz with r values of 0.497, 0.488 and 0.260, respectively and a moderate positive correlation at 4000 Hz with r value of 0.691 (Table 7).

Table 7. Correlation between PTA and ASSR & PTA and ABR among normal hearing group (N=22)

	Pearson rank correlation (r)	P value
ASSR (Hz)		
500	0.776	<0.001
1000	0.563	0.006
2000	0.506	0.016
4000	0.824	<0.001
ABR (Hz)		
500	0.497	0.019
1000	0.488	0.021
2000	0.260	0.243
4000	0.691	<0.001

Overall (n=80) there was a strong positive correlation between PTA and ASSR across all frequencies with r values 0.767, 0.815, 0.877 and 0.889 at 500 Hz, 1000 Hz, 2000 Hz and 4000 Hz, respectively (p-value: <0.001). Similarly, there was a strong positive correlation between PTA and ABR across all frequencies with r values 0.832, 0.801, 0.907 and 0.895 at 500 Hz, 1000 Hz, 2000 Hz and 4000 Hz, respectively (p-value: <0.001) (Table 8 & Figures 1 to 8).

The reliability of both the methods (ASSR and ABR) was good in assessing hearing threshold at different frequencies with the ICC value of 0.75, 0.809, 0.873 and 0.888 at 500 Hz, 1000 Hz, 2000 Hz and 4000 Hz, respectively for ASSR and ICC value of 0.828, 0.791, 0.905 and 0.895 at 500 Hz, 1000 Hz, 2000 Hz and 4000 Hz, respectively for ABR.
The reliability reported in all the scenarios was statistically significant (P value<0.001) (Table 9).

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Table 8. Correlation between PTA and ASSR & PTA and ABR in the study population (N=80)

	Pearson rank correlation (r)	P value
ASSR (Hz)		
500	0.767	<0.001
1000	0.815	<0.001
2000	0.877	<0.001
4000	0.889	<0.001
ABR (Hz)		
500	0.832	<0.001
1000	0.801	<0.001
2000	0.907	<0.001
4000	0.895	<0.001

Table 9. Intra class correlation coefficient (measure of reliability) between PTA and ASSR/ ABR in the study population (N=80)

Frequency (Hz)	ASSR		ABR	
	Intra class Correlation (95% CI)	P value	Intra class Correlation (95% CI)	P Value
500	0.755 (0.642, 0.863)	<0.001	0.828 (0.744, 0.886)	<0.001
1000	0.809 (0.718, 0.873)	<0.001	0.791 (0.692, 0.861)	<0.001
2000	0.873 (0.808, 0.916)	<0.001	0.905 (0.856, 0.938)	<0.001
4000	0.888 (0.831, 0.927)	<0.001	0.895 (0.840, 0.931)	<0.001

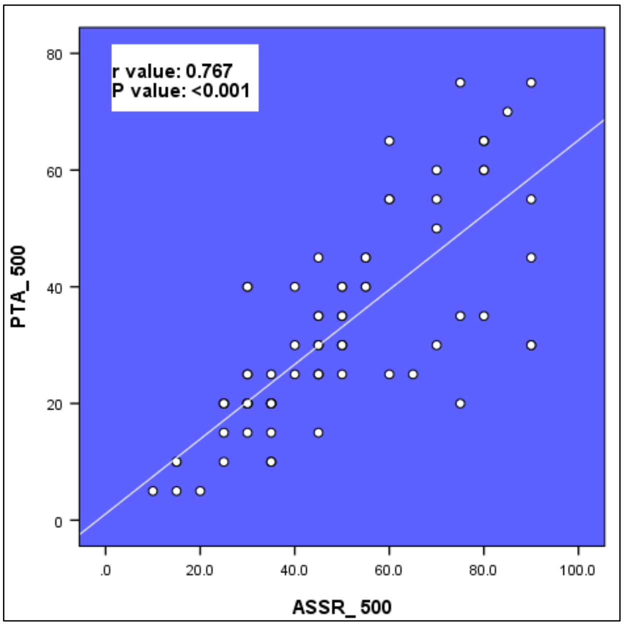

Figure 1. Scatter plot diagram of correlation between PTA-500 Hz and ASSR-500 Hz (N=80).

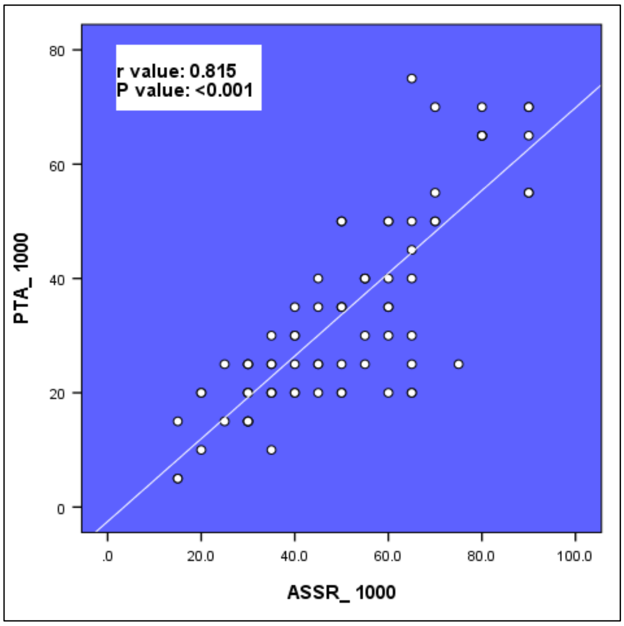

Figure 2. Scatter plot diagram of correlation between PTA-1000 Hz and ASSR-1000 Hz (N=80).

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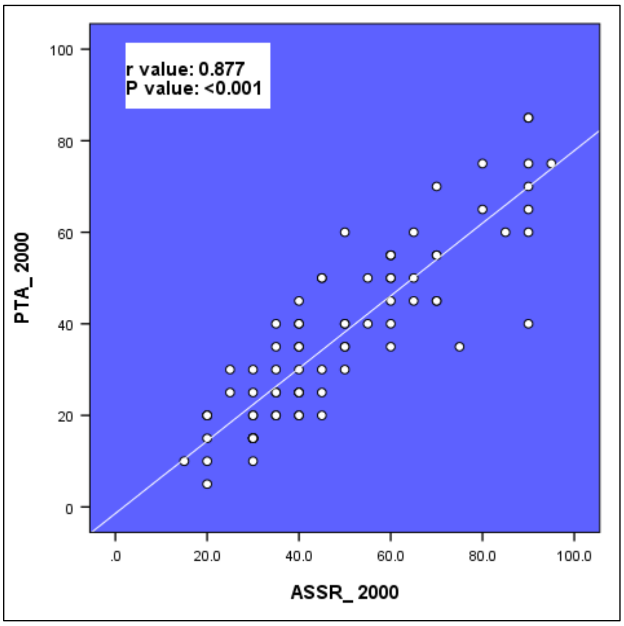

Figure 3. Scatter plot diagram of correlation between PTA-2000 Hz and ASSR-2000 Hz (N=80).

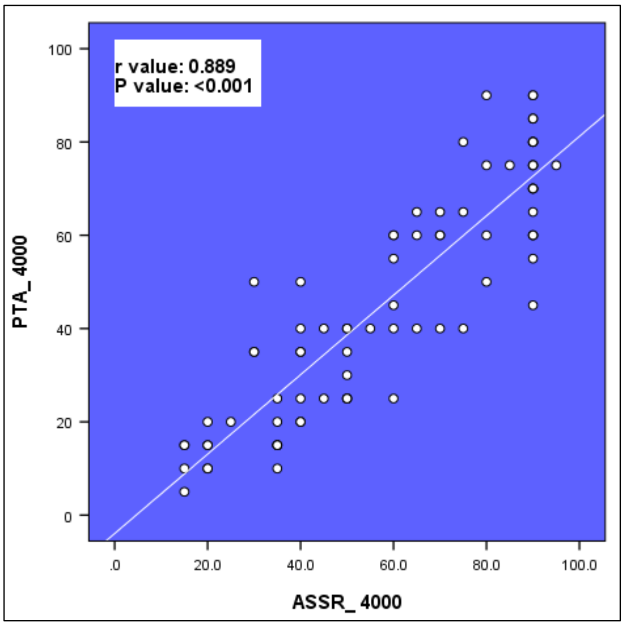

Figure 4. Scatter plot diagram of correlation between PTA-4000 Hz and ASSR-4000 Hz (N=80).

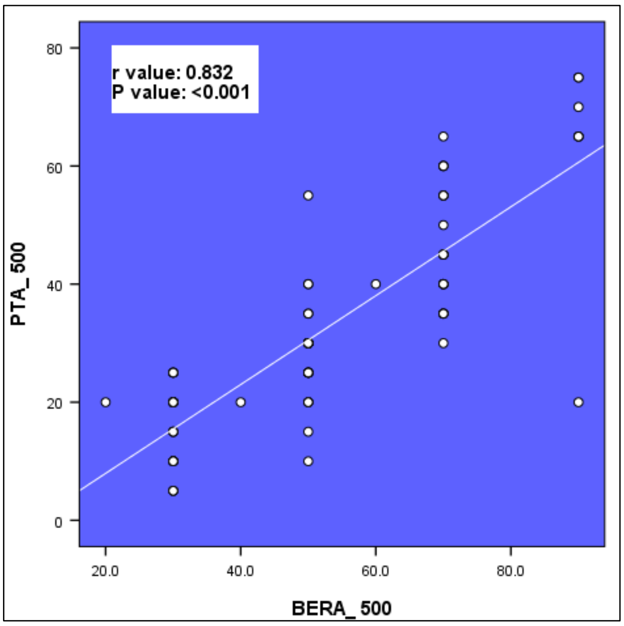

Figure 5. Scatter plot diagram of correlation between PTA-500 Hz and ABR-500 Hz (N=80).

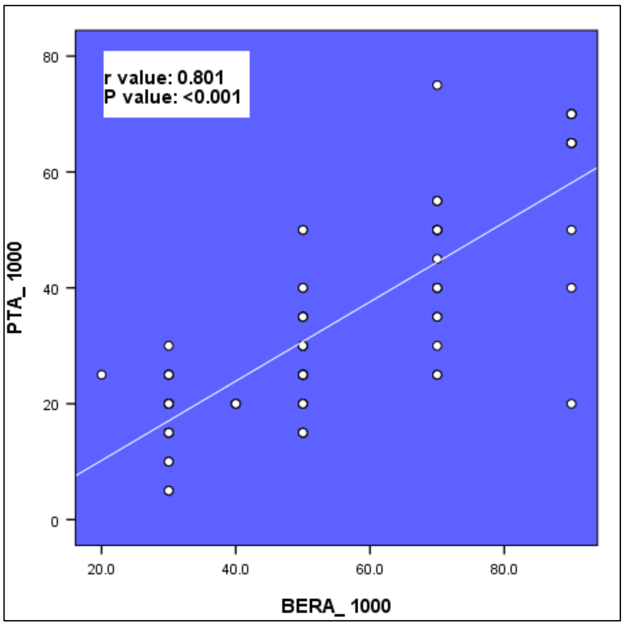

Figure 6. Scatter plot diagram of correlation between PTA-1000 Hz and ABR-1000 Hz (N=80).

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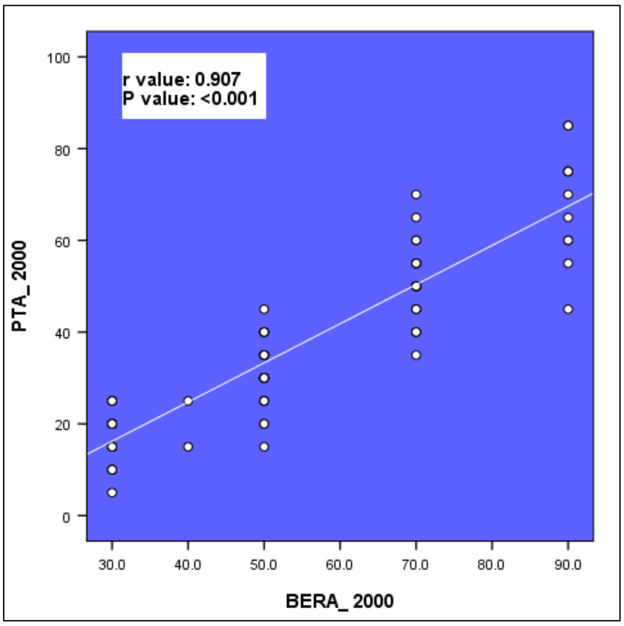

Figure 7. Scatter plot diagram of correlation between PTA-2000 Hz and ABR-2000 Hz (N=80).

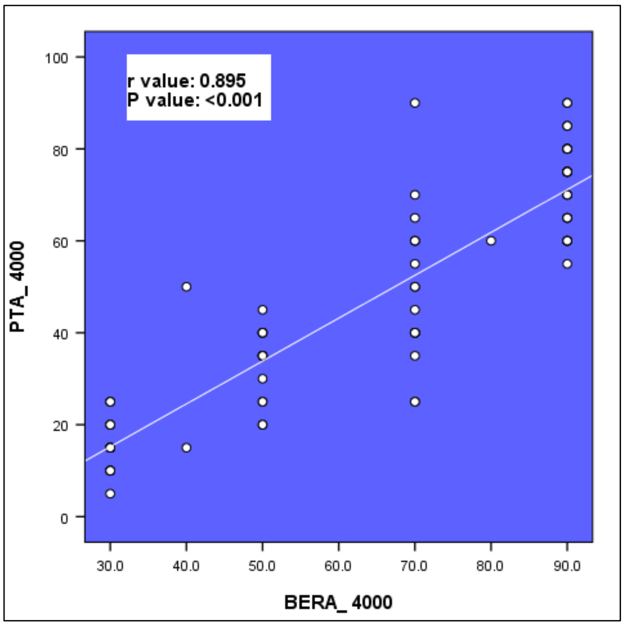

Figure 8: Scatter plot diagram of correlation between PTA-4000 Hz and ABR-4000 Hz (N=80).

Discussion

In this study, we have compared ASSR and ABR with PTA in an adult population. We found that the difference between mean PTA thresholds and mean ASSR thresholds was lesser than the difference between mean PTA thresholds and mean ABR thresholds in all three groups across all frequencies (Table 2-4). Yu-Hsing Lin et al. also noted similar findings in their study with the mean difference between pure-tone thresholds and ASSR thresholds of all subjects were lesser (15.4 dB) than the mean difference between pure-tone thresholds and ABR thresholds of all subjects (20.1 dB) (15). Johnson TA et al. also observed that the ABR underestimated the degree of hearing loss by as much as 25 dB at 1.5 and 2 kHz however ASSR was recorded within 5 to 10 dB of the behavioral threshold (16). These findings coincided with our study. In our study, the average difference score between PTA and ASSR was 14.2 dB and the same between PTA and ABR was 18.8 dB. Hence, ASSR thresholds were closer to the pure tone thresholds. The mean difference score was smaller at higher frequencies. We noticed that the correlation between ASSR/ABR and PTA was better in SNHL and CHL groups than in the normal hearing group. There was no significant difference between SNHL and CHL group. The correlation was worst between PTA and ABR in normal hearing group at 1 kHz and 2 kHz. Johnson TA et al. also noted that ASSR and ABR were consistently recorded closer to the behavioral thresholds in the hearing-impaired groups than in normal hearing group (16). Similar findings were confirmed in other studies also (17-21).

Wadheera et al. for example, postulated a close correlation between ASSR and PTA thresholds in patients with SNHL and CHL, but the correlation was weaker for the normal hearing group (18). In their SNHL group, the r values were 0.68-0.82 across all frequencies. In their CHL group, r values were 0.62-0.66 across all frequencies. However, in Normal hearing group r values were -0.17, 0.01, 0.03, -0.32 at 0.5, 1.0, 2.0, and 4.0 kHz, respectively. Similarly, studies done by Stapells et al. highlighted differences between ABR and pure-tone behavioral thresholds were reduced in subjects with SNHL compared to normal hearing subjects (21).

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We also examined the overall correlation between PTA-ASSR and PTA-ABR thresholds which were found to be stronger across all frequencies. Similar findings were observed in the study done by Yu-Hsing Lin et al. They found the correlation coefficients (r) between PTA and ASSR were 0.89, 0.95, 0.96, and 0.97 at frequencies of 0.5, 1, 2, and 4 kHz, respectively ($p < 0.01$) and the correlation coefficient (r) between high-frequency pure-tone and ABR thresholds was 0.93 ($p < 0.01$) (15). Cone-Wesson B et al also noticed a strong and statistically significant correlation between PTA and ASSR as well as PTA and ABR with Pearson correlation coefficient ranging from 0.77 to 0.82 for ABR and 0.77 to 0.88 for ASSR (22). We observed that correlation was better in higher frequency for both ASSR and ABR. These findings were corresponding to other studies (17,23) (Figures 1-8). In our study, the overall reliability of both ASSR and ABR was good across all frequencies as depicted by Intra class correlation coefficient (ICC) however ICC value was better in high frequency for both ASSR and ABR which coincide with the study done by Yu-Hsing Lin et al. (15) stating that the correlation of evoked response and behaviour threshold decreases at a lower frequency (Table 9). PTA can be represented in terms of ASSR and ABR by the equation derived by regression:

PTA = Beta (ASSR or ABR) ± constant

Mean PTA = 0.846 (ASSR mean) - 6.335

Mean PTA = 0.867 (ABR mean) – 11.303

In our study, we also noticed that ASSR has several advantages over ABR. Firstly, ASSR thresholds of all four frequencies can be recorded simultaneously for both ears in lesser time. Vander Werff et al. (24) and Van Maanen et al. (25) also derived that ASSR has advantages in terms of test times and frequency specificity in comparison with ABR. Secondly, the ASSR software can automatically detect response, hence the interpretation is absolutely objective (26-27). ABR also hasthe disadvantage of not being able to identify hearing loss over 90 dB as this range is beyond its detection limit (28).

The main limitation of this study was the small number of the study population as performing all three tests in the same subject was a time-consuming process.

Conclusion

The present study correlated pure tone audiometry with two objective tests of hearing-ASSR and ABR in the adult population. The results of this study concluded that both ABR and ASSR can be used to predict frequency-specific hearing thresholds. The correlation was better in SNHL and CHL groups and least in the normal hearing group. The mean difference between ASSR, ABR and PTA was larger at lower frequencies than at higher frequencies. The best correlation was found at 4 kHz for ASSR and at 2 kHz for ABR.

The mean difference between ASSR and PTA was smaller than the mean difference between ABR and PTA. Hence, ASSR was more reliable than ABR for accurate prediction of frequency specific hearing threshold as they were closer to the PTA threshold.

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Not declared.

Conflicts of Interest

The authors declare no conflicts of interest.

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Ethics

The study was approved by the Institutional Ethical Committee of Command Hospital Air Force (Bangalore) with reference number: CHAFB/1911/12/IEC

Authors Contributions

JB and RN analyzed and interpreted the patient data. HS, PKS and JB are the major contributors in writing the manuscript. All authors read and approved the final manuscript.

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