How to Cite:
Mohamed, S. F., Dabbous, A., El-Shennawy, A., & Hamdy, M. (2022). Does frequency-specific cortical auditory evoked potential accurately reflect the behavioural hearing threshold?. *International Journal of Health Sciences*, *6*(S4), 2464–2485. https://doi.org/10.53730/ijhs.v6nS4.7194

Does frequency-specific cortical auditory evoked potential accurately reflect the behavioural hearing threshold?

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***Abstract*---**Background: One of the most important and clinically useful aspects of the CAEP is that in adults, the response can be observed close to, and therefore can be used as an objective estimator of the auditory threshold. This has obvious applications in patients that cannot or will not produce reliable responses during pure tone audiometry (PTA). Objectives: to correlate the hearing threshold level measured objectively by N1-P2 CAEP at different tonal frequencies to behavioural hearing threshold level. Methods: Included 77 adult subjects. Hearing threshold was measured behaviourally by PTA then objectively by N1-P2 CAEP. Ears were divided into similar degree of hearing /hearing loss et each frequency in each group to resemble a flat audiogram configuration. Results: There were no statistically significant differences between PTA threshold and N1P2 threshold at the four tested frequencies in the different hearing degrees groups of the study, except for statistically significant lower N1P2 threshold than PTA threshold in the profound hearing loss group at 1000 and 2000 Hz. And in each of the moderate, moderately severe, Severe and profound hearing loss groups at 4000 Hz. There were no statistically

Manuscript submitted: 27 March 2022, Manuscript revised: 18 April 2022, Accepted for publication: 9 May 2022

significant differences among the hearing degrees groups of the study, regarding (PTA-N1P2) threshold difference at 500 Hz and at 2000 Hz. But there was a statistically significant lower PTA-N1P2 threshold difference in moderately severe than the normal and profound hearing loss groups, and significant lower PTA-N1P2) threshold difference in mild than profound hearing loss group, at 1000 Hz. As well as a statistically significant higher PTA-N1P2 threshold difference in the moderately severe than the Normal and mild hearing loss groups and in the profound than the Normal, mild and moderate hearing loss groups at 4000 Hz. In all 6 degrees of hearing groups, there was no statistically significant difference in comparison among the different frequencies regarding the PTA-N1P2 difference. Conclusion: The N1P2 CAEP is equally accurate in estimating the PTA threshold at all 4 tested frequencies in any degree of hearing: either the normal hearing ears, ears with mild, moderate, moderately severe, severe or profound SNHL. N1P2 was equally accurate in estimating the PTA threshold at all hearing degrees at 500 Hz and at 2000 Hz, while at 1000 Hz and 4000 Hz, the difference was smaller at less severe degrees of hearing loss.

***Keywords*---**Frequency-Specific, hearing loss, Objective Hearing threshold test, N1P2 Cortical auditory evoked potential.

Introduction

The auditory evoked potentials (AEPs) are electrical modifications in the auditory nervous system, generated in several levels of the central auditory nervous system by an acoustic stimulus. They are classified according to latency (interval of time between the presentation of the sound stimulus and wave peak) into three groups: short-latency potentials, occurring in the first 10–12 milliseconds (ms); middle-latency potentials, occurring between 12 and 50 ms; and long-latency potentials, also called cortical potentials, occurring between 50 and 600 ms (Hall, 2007).

The most common exogenous cortical auditory evoked potentials (CAEPs) are P1, N1 and P2. These components provide information concerning the arrival of sound information to the auditory cortex. It represents summed neural activity in the auditory cortex in response to the onset, change, or the offset of a sound. The CAEP in adults consists of a positive peak (PI) occurring around 50 ms post-stimulus followed by a negative deflection (Nl) around 100 ms and another positive peak (P2) around 180 ms (Martin et al., 2007).

N1 and P2 are thought to have multiple generators in Heschl's gyrus (auditory cortex) and have latencies of 100-160 ms and 160 - 270 ms respectively, depending on the sensation level of the stimulus (Lightfoot, 2010).
This response is “obligatory” because it is evoked irrespective of whether the person is attending to the sound or not. The presence of the P l-N1-P2 complex indicates that the stimulus has been detected at the level of the auditory cortex (Hyde, 1997).

The N1-P2 CAEP response can be used as an electrophysiological measure in the estimation of hearing sensitivity in adults where no reliable behavioral threshold could be obtained (Lightfoot and Kennedy, 2006).

The auditory assessment using the CAEPs presents several advantages, because it allows evaluating the whole auditory system (from the brain stem to the cortex), and because it can be registered among awake participants, obtained with a variety of acoustic stimuli (Golding et al., 2009).

Also, it is possible to use longer duration tone-bursts than those used for auditory brainstem response recordings, which result in more frequency specificity (Lightfoot and Kennedy, 2006).
The CAEP may be evoked by the onset (from silence) of an audible stimulus, to stimulus offset, or to an abrupt change (e.g., frequency, phase, temporal or level change) in a continual stimulus. This has important implications for the choice of tone burst duration and for the use of speech tokens as stimuli (Weber, 1970).
Unlike conventional PTA, CAEP testing requires that the patient be alert but not physically active. In adult testing this is most conveniently achieved by asking the patient to read a magazine or watch a silent video (Lavoie et al., 2008).

The level of subject arousal, alertness, and attention are known to influence the latency, amplitude, or variability of the N1-P2 response. In general, a larger or less variable response is recorded when the subject is asked to read a book or attend to the stimuli (listen to or count the stimuli) rather than simply sit with eyes open (Lightfoot, 2010).

It is generally held that the N1-P2 response is attenuated by sleep (which is therefore to be avoided when testing), but many studies have shown a more complex picture, in which response latencies increase during the stages of sleep but the amplitude of the response may either increase or decrease, depending on the sleep stage (Campbell and Colrain, 2002).

One of the most important and clinically useful aspects of the CAEP is that in adults, the response can be observed close to, and therefore can be used as an objective estimator of the auditory threshold. This has obvious applications in patients that cannot or will not produce reliable responses during (PTA) (Tsui et al., 2002). Lightfoot and Kennedy (2006) identified a mean audiometric / electrophysiological threshold difference of 6.5 dB, after correction. That's better than most estimates of adult ABR accuracy.

Cortical auditory evoked potential (CAEP) has advantages over the tone-evoked auditory brainstem response (ABR) (Lightfoot and Kennedy, 2006) and the auditory steady state response (ASSR) recording (Tomlin et al., 2006). N1-P2 response provide the almost ideal frequency specificity allowing steeply sloping or notched audiometric contours to be resolved. Unlike the ABR, the morphology of the N1-P2 response is every bit as clear for low frequencies as for high frequencies. Response amplitude does decline at frequencies above about 3 kHz but the threshold prediction at 8 kHz was found to be no worse than at lower frequencies. In addition to the excellent frequency specificity and good threshold precision, other advantages over the ABR include testing the integrity of a greater proportion of the auditory nervous system and the capability to employ speech-based stimuli (Lightfoot, 2010).

CAEP was found to provide responses closer to threshold than the ASSR. The CAEP has demonstrated a closer relationship of evoked potential threshold with behavioural hearing levels compared to the 40 Hz ASSR. CAEP has demonstrated significantly lower variance in results than the ASSR (Tomlin et al., 2006).

Rationale

The CAEP showed advantages over previous frequency specific evoked potentials in hearing threshold estimation in adults. To the best of our knowledge, previous research studied this correlation in groups of individuals with average degrees of behavioural hearing losses, which would not necessarily indicate flat audiogram configuration. So, it would be better to group frequencies with similar degrees of hearing /hearing loss, instead of using an average of tested frequencies as the grouping method, which may be misleading as it would not reflect the configuration of the audiogram.

Aim of the Work

To correlate the hearing threshold level measured objectively by N1-P2 CAEP at different tonal frequencies to behavioural hearing threshold level at each respective frequency, in each degree of hearing loss.

Subjets & Methods
Participants

The study consisted of 77 subjects. Patients were collected from Audiology Unit outpatient clinic, Otorhinolaryngology department, Nasser Institute and Audiology Unit outpatient clinic, Otorhinolaryngology department, in Kasr Al-Ainy hospital, Cairo University; in the period from November 2017 to November 2018. After Medical ethics committee approval, they included adults of both genders with age range between 20-60 years,

Ear groups were divided into degrees of HL, not according to the mean threshold of the 4 frequencies: 500, 1000, 2000 and 4000Hz, because this would have included different configuration audiograms for the hearing loss, which would affect the results, as this may be misleading as it would not reflect the configuration of the audiogram. Instead, the ears were divided into similar degree of hearing /hearing loss et each frequency in each group, to resemble a flat audiogram. This ensured each group of hearing /hearing loss degree to have homogenous values.to accurately reflect flat audiogram configuration for all groups. i.e., the normal hearing threshold level ear group included ears having normal hearing threshold level at 4 frequencies tested, and the mild SNHL ear group included ears having mild SNHL at 4 frequencies tested, etc…
Based on the PTA hearing threshold level (HTL) average of 500, 1000, 2000 and 4000 Hz:

1. Normal hearing ears: at all 4 frequencies: 500, 1000, 2000 and 4000 Hz: PTA average up to 25dBHL.

2. Mild SNHL Ears: PTA at all 4 frequencies: 500, 1000, 2000 and 4000 Hz: 26-40 dBHL.
3. Moderate SNHL Ears: PTA at all 4 frequencies: 500, 1000, 2000 and 4000 Hz: 41-55 dBHL.
4. Moderately severe SNHL Ears: PTA at all 4 frequencies: 500, 1000, 2000 and 4000 Hz: 56-70 dBHL.
5. Severe SNHL Ears: PTA at all 4 frequencies: 500, 1000, 2000 and 4000 Hz: 71-90 dBHL.
6. Profound SNHL Ears: PTA at all 4 frequencies: 500, 1000, 2000 and 4000 Hz: 91+ dBHL

With exclusion of conductive hearing loss, unilateral hearing loss and neurological diseases.

Procedure

All participants included in this study were subjected to: 1) Detailed history taking; including: Personal history; as age, gender and special habits of medical importance. Present history: with complete analysis of the hearing loss and any associated symptoms. Past history: of local ear diseases, systemic diseases affecting hearing, Drug intake especially ototoxic drugs or trauma to the ear or head. Family history: of consanguinity or hearing loss. 2) Otologic Examination including otoscopy and tuning fork tests. 3) Audiometric assessment in Sound treated room, Amplisilence model E. using Pure tone audiometer: Itera II, Madsen Otometrics calibrated according to ISO standards; including Pure tone audiometry (*PTA*): Air conduction in the frequency range of 250 - 8000 Hz. Bone conduction in the frequency range of 500 - 4000 Hz. Speech audiometry including *Speech reception threshold* (SRT): using Arabic spondaic words (Soliman et al., 1985). *Word discrimination score*; using Arabic phonetically balanced (PB) words (Soliman, 1976).4) Immittancemetry: using Immittancemeter: Madsen Zodiac 901 middle ear analyzer (GN Otometrics, Denmark), calibrated according to ISO standards. Acoustic reflexes were tested at frequencies of 500–4000 Hz including single component, single frequency tympanometry with 226 Hz probe tone. *Acoustic reflexes threshold:* using pure tones at frequencies 500, 1000, 2000, 4000 HZ. 5) Hearing threshold estimation using CAEP: Recording the N1-P2 response for tone burst stimuli for frequencies 500,1000, 2000, and 4000 Hz by two channels Neuro-Audio (Neurosoft Ltd, Russia) Auditory evoked potential. After cleaning the skin, surface electrodes were positioned. All subjects were asked to remain seated quiet but awake and reading a magazine. They were informed that test was automatic. Recording electrodes: The CAEP signal was recorded with electrode placements: non-inverting electrode was placed on the high forehead, inverting electrode on the right or left mastoid (M1 and M2), whereas ground electrode was placed on the other mastoid. The electrode impedance was maintained for all electrodes below 5kΩ during the testing. Stimuli were created for CAEP using (Neurosoft) system, and presented by air conduction using insert earphone EAR-3A10Ω. The stimuli were tone burst having 10-msec linear rise/fall times ms at frequencies of 1 kHz and above (20 ms at lower frequencies) and 60-msec plateau time. Stimulations used presented at intensity of 25 dBSL (25 dB above threshold established from the subject PTA) at rate of 1.1 pulse/ sec. A total number of 250 sweeps were collected. N1P2 morphology was evaluated, and waveforms were judged based on visual inspection of the recordings. Descending intensities in steps of 10 dB and ascending intensities of 5 dB were used up to the minimum threshold of automatic response detection. The maximum stimulus was 100dB.

Response analysis

N1 was defined as the first robust negativity in waveform in the latency range from 100-160 msec. P2 was defined as the positive waveform following N1 in the latency range from 160-270 msec. N.B. For profound hearing loss, the no response values in PTA were entered as 120dB for statistical dealing with data without zero or missing values for the entry. Similarly for profound hearing loss, the no response values for N1P2 CAEP, the threshold exceeding the maximum stimulus given 100dB, was entered as 110dB for statistical dealing with data without zero or missing values for the entry. N.B. Negative sign removed from the PTA- CAEP difference at the respective frequency, to get accurate average of the absolute values of the difference.

Statistical Methods

Data were entered in excel, then coded and entered using the statistical package SPSS (Statistical Package for the Social Sciences) version 25. Data was summarized using mean, standard deviation, minimum and maximum in quantitative data and using frequency (count) and relative frequency (percentage) for categorical data. Comparisons between quantitative variables were done using the one-way ANOVA test and post-hoc LSD tests. For comparison of paired measurements within each patient the paired t-test was used. For comparing categorical data, Chi square ($\chi 2$) test was performed. Correlations between quantitative variables were done using Pearson correlation coefficient (r). P-values less than 0.05 were considered as statistically significant.

Results

The study included 149 ears of 77 adult subjects of both genders, whose mean age was 39.51 ± 10.10 years. There was no statistically significant difference among the ear groups under study as regards gender X_2=0.702, p=0.983; X_2=6.400, p=0.269; X_2=5.182, p=0.394; X_2=6.375, p=0.271; for groups of ears for 500 Hz, 1000Hz, 2000Hz and 4000Hz respectively.
Table (1) shows the distribution of groups of ears in this study into 6 hearing groups: Normal, Mild, Moderate Moderately Severe, Severe and Profound SNHL ears. Each group consists of 4 frequencies to be tested 500Hz, 1000Hz, 2000Hz and 4000Hz, having the same hearing degree.

Table (1)
The distribution of groups of ears in this study

			Ears						Total
			Normal	Mild	Moderate	Moderately Severe	Severe	Profound	
Frequency	500Hz	No.	48	22	27	24	17	11	149
		%	31.58%	26.83%	36.99%	23.53%	16.83%	12.79%	
	1000Hz	No.	44	23	13	23	28	18	149
		%	28.95%	28.05%	17.81%	22.55%	27.72%	20.93%	
	2000Hz	No.	36	23	14	30	22	24	149
		%	23.68%	28.05%	19.18%	29.41%	21.78%	27.91%	
	4000Hz	No.	24	14	19	25	34	33	149
		%	15.79%	17.07%	26.03%	24.51%	33.66%	38.37%	
Total		No.	152	82	73	102	101	86	
		%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	

X_2= 38.071; p= 0.001

Table (2)
Comparison between the PTA threshold and N1P2 threshold in ears groups under study at 500Hz

	PTA 500					CAEP 500					t	p
	No.	Mean	SD	Min	Max	No.	Mean	SD	Min	Max		
Normal	48	18.85	5.38	10	25	48	19.48	9.52	5	40	-0.507	0.615
Mild	22	35.00	4.36	30	40	22	35.68	7.61	15	45	-0.591	0.561
Moderate	27	49.44	3.76	45	55	27	51.48	6.02	40	65	-1.618	0.118
Moderately severe	24	64.17	4.34	60	70	24	67.08	9.08	50	95	-1.834	0.080
Severe	17	82.94	5.32	75	90	17	85.29	9.10	70	100	-1.095	0.290
Profound	11	105.91	9.44	95	120	11	99.09	7.01	90	110	1.753	0.110
Total	149	47.82	27.55	10	120	149	48.72	27.74	5	110	-0.283	0.777

(table 2) shows the mean, standard deviation, minimum and maximum values of hearing threshold levels using PTA and N1P2 in all degrees of hearing groups at 500Hz.
There were no statistically significant differences between PTA threshold and N1P2 threshold at 500 Hz, in the different hearing degree groups of the study.

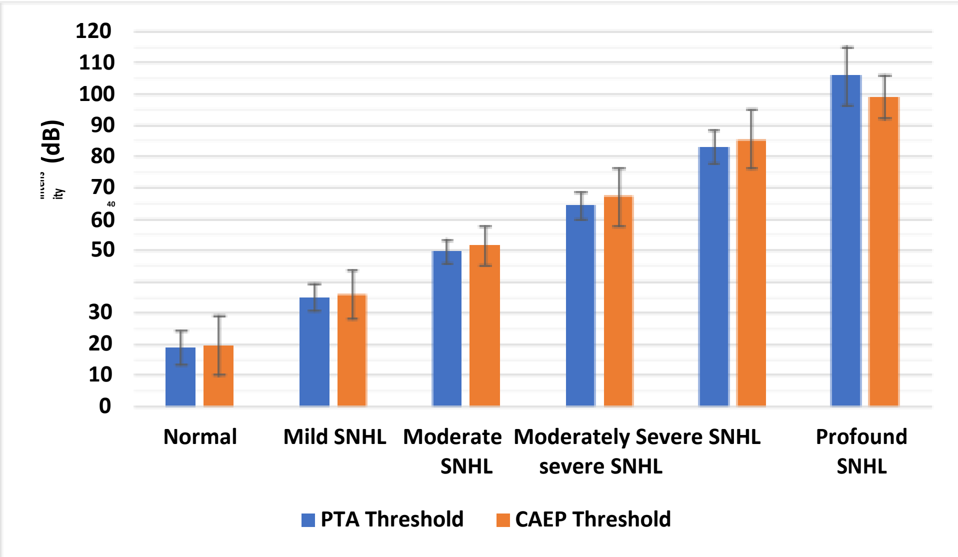

Fig 1: PTA threshold and N1P2 threshold in ears groups under study at 500Hz.

Table (3)
Comparison between the PTA threshold and N1P2 threshold in ears groups under study at 1000Hz

	PTA 1000					CAEP 1000					T	p
	No.	Mean	SD	Min	Max	No.	Mean	SD	Min	Max		
Normal	44	20.11	5.76	5	25	44	20.45	9.14	5	40	-0.238	0.813
Mild	23	35.00	4.77	30	40	23	36.96	7.35	25	55	-1.899	0.071
Moderate	13	48.46	4.27	45	55	13	47.31	8.57	30	65	0.542	0.598
Moderately severe	23	65.87	3.89	60	70	23	64.13	7.18	50	75	1.447	0.162
Severe	28	80.00	5.77	75	90	28	78.21	9.83	60	100	1.243	0.225
Profound	18	106.39	9.20	95	120	18	99.72	8.99	85	110	4.408	0.000
Total	149	53.62	30.27	5	120	149	52.52	28.90	5	110	0.323	0.747

(table 3) showed the mean, standard deviation, minimum and maximum values of hearing threshold levels using PTA and N1P2 in all groups at degrees of hearing 1000Hz. There were no statistically significant differences between PTA threshold and N1P2 threshold at 1000 Hz, in the different hearing degree groups of the study, except for a statistically significant lower N1P2 threshold than PTA threshold in the profound hearing loss group.

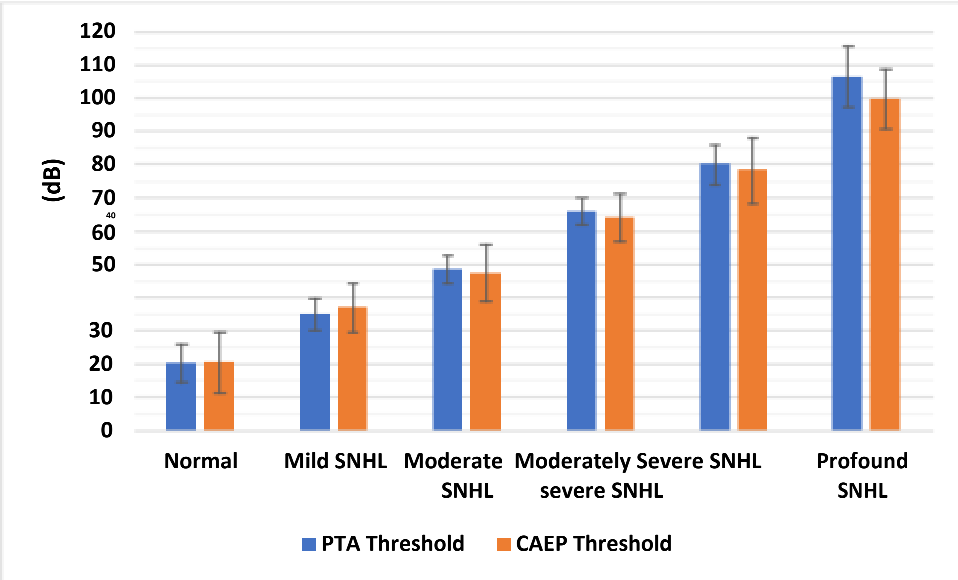

Fig 2: PTA threshold and N1P2 threshold in ears groups under study at 1000Hz.

Table (4)
Comparison between the PTA threshold and N1P2 threshold in ears groups under study at 2000Hz

	PTA 2000					CAEP 2000					T	P
	No.	Mean	SD	Min	Max	No.	Mean	SD	Min	Max		
Normal	36	19.31	5.75	10	25	36	19.58	8.23	5	35	-0.195	0.846
Mild	23	35.43	4.24	30	40	23	32.61	9.52	15	50	1.481	0.153
Moderate	14	49.64	3.65	45	55	14	48.21	7.75	30	60	0.888	0.391
Moderately severe	30	64.67	5.07	50	70	30	62.17	10.88	35	90	1.559	0.130
Severe	22	82.05	5.27	75	90	22	79.55	9.87	60	95	1.254	0.224
Profound	24	108.75	9.12	95	120	24	99.79	8.01	80	110	9.014	0.000
Total	149	57.45	31.56	10	120	149	54.63	29.90	5	110	0.791	0.429

(table 4) showed the mean, standard deviation, minimum and maximum values of hearing threshold levels using PTA and N1P2 in all degrees of hearing groups at 2000Hz. There were no statistically significant differences between PTA threshold and N1P2 threshold at 2000 Hz, in the different hearing degree groups of the study, except in the profound hearing loss group.

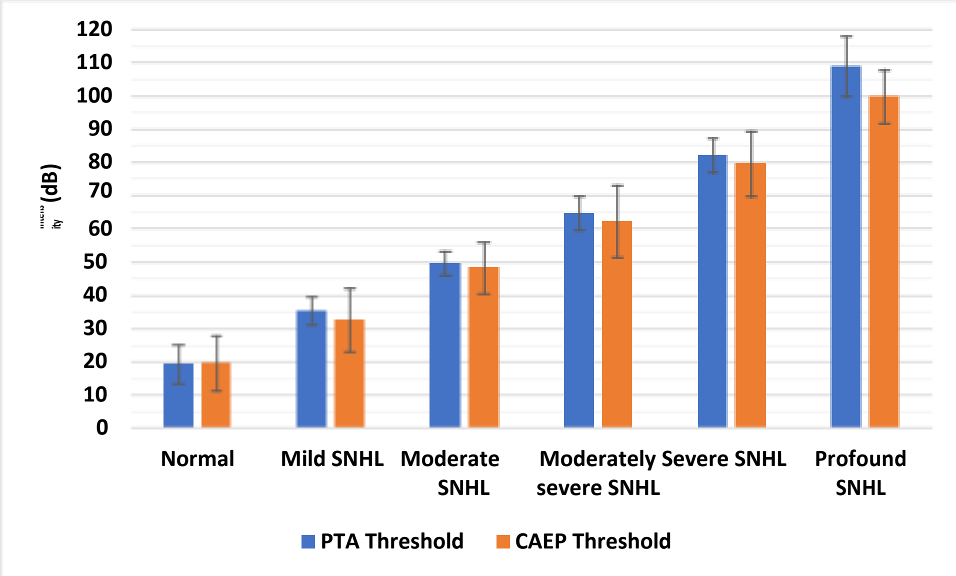

Fig 3: PTA threshold and N1P2 threshold in ears groups under study at 2000Hz.

Table (5)
Comparison between the PTA threshold and N1P2 threshold in ears groups under study at 4000Hz.

	PTA 4000					CAEP 4000					T	p
	No.	Mean	SD	Min	Max	No.	Mean	SD	Min	Max		
Normal	24	18.13	5.07	10	25	24	16.46	6.99	5	25	0.707	0.486
Mild	14	37.14	3.23	30	40	14	33.93	6.84	15	40	1.979	0.069
Moderate	19	50.53	3.69	45	55	19	46.32	7.23	30	60	2.388	0.028
Moderately severe	27	66.30	4.06	60	70	27	61.30	9.96	40	80	2.413	0.024
Severe	32	82.50	6.22	75	90	32	79.06	9.20	55	95	2.480	0.018
Profound	33	110.00	9.76	95	120	33	101.06	8.91	75	110	6.283	0.000
Total	149	66.95	31.77	10	120	149	62.21	30.27	5	110	1.316	0.189

(table 5) showed the mean, standard deviation, minimum and maximum values of hearing threshold levels using PTA and N1P2 in all groups degrees of hearing at 4000Hz. There was a statistically significant difference between the N1P2 threshold than PTA threshold in the Moderate, moderately severe, Severe and profound hearing loss groups

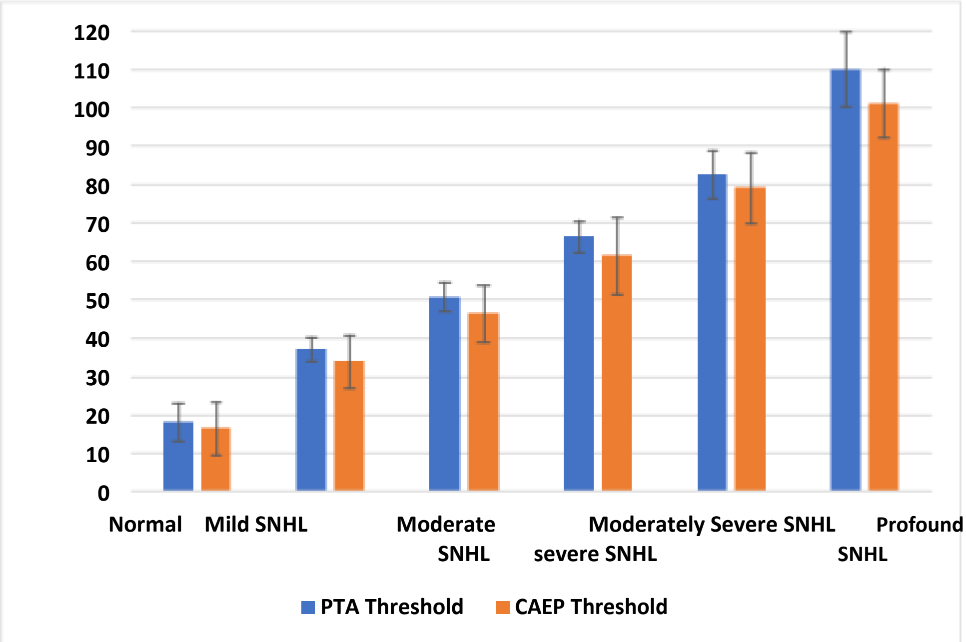

Fig 4: PTA threshold and N1P2 threshold in ears groups under study at **4**000Hz.

Table (6)
Comparison of PTA-N1P2 threshold difference among the different hearing level ear groups, at 500Hz.

At 500Hz:		No.	Mean	SD	Min	Max	F	P
PTA-CAEP Difference *	Normal	48	6.8750	5.01	0.00	15.00	2.203	0.057
	Mild	22	3.8636	3.76	0.00	15.00		
	Moderate	27	4.6296	4.99	0.00	20.00		
	Moderately severe	24	6.2500	5.37	0.00	25.00		
	Severe	17	7.0588	5.61	0.00	20.00		
	Profound	11	9.5455	10.83	0.00	30.00		
	Total	149	6.1409	5.70	0.00	30.00		

*Negative sign removed to get the absolute values of the difference.

Table (6) showed no statistically significant differences among the different groups of the study, regarding (PTA-N1P2) threshold difference at 500 Hz.

Table (7)
Comparison of PTA-N1P2 threshold difference among the different hearing level ear groups, at 1000Hz.

At 1000Hz:		No.	Mean	SD	Min	Max	F	P
PTA-CAEP Difference *	Normal	44	7.16	6.14	0	20	2.457	0.036
	Mild	23	3.70	3.76	0	15		
	Moderate	13	5.00	5.77	0	20		
	Moderately severe	23	3.91	4.51	0	15		
	Severe	28	5.36	5.60	0	20		
	Profound	18	7.78	4.92	0	20		
	Total	149	5.67	5.44	0	20		

*Negative sign removed to get the absolute values of the difference.

Post Hoc Tests, PTA-CAEP Difference 1000*		
		p value
4	1	0.019
	6	0.022
6	2	0.016

Table (7) showed statistically significant differences among the different groups of the study, regarding (PTA-N1P2) threshold difference at 1000 Hz with absolute values further analysis post-hoc test showed that the statistically significant differences were found between profound hearing loss and other groups. Post-hoc test showed that the statistically significant differences were found between moderately severe and normal hearing, moderately severe and profound hearing losses, profound and mild hearing loss in absolute values.

Table (8)
Comparison of PTA-N1P2 threshold difference among the different hearing level ear groups, at 2000Hz.

At 2000Hz:		No.	Mean	SD	Min	Max	F	P
PTA-CAEP Difference *	Normal	36	5.83	6.15	0	25	1.740	0.129
	Mild	23	7.17	6.18	0	25		
	Moderate	14	4.29	4.32	0	15		
	Moderately	30	6.17	6.65	0	30		

		No.	Mean	SD	Min	Max	F	p
	severe							
	Severe	22	6.59	6.97	0	25		
	Profound	24	9.79	6.83	0	25		
	Total	149	6.71	6.44	0	30		

*Negative sign removed to get the absolute values of the difference.

Table (8) showed no statistically significant differences among the different groups of the study, regarding (PTA-N1P2) threshold difference at 2000 Hz with absolute values.

Table (9)
Comparison of PTA-N1P2 threshold difference among the different hearing level ear groups, at 4000Hz.

At 4000Hz:		No.	Mean	SD	Min	Max	F	p
PTA-CAEP Difference *	Normal	24	4.58	4.64	0	15	3.681	0.004
	Mild	14	4.64	4.99	0	15		
	Moderate	19	5.79	6.51	0	20		
	Moderately severe	27	8.70	6.29	0	20		
	Severe	32	7.50	5.68	0	20		
	Profound	33	10.15	6.55	0	20		
	Total	149	7.35	6.17	0	20		

*Negative sign removed to get the absolute values of the difference.

Post Hoc Tests, PTA-CAEP Difference 4000*		
		p value
4	1	0.014
	2	0.039
6	1	0.001
	2	0.004
	3	0.011

Table (9) showed statistically significant differences among the different groups of the study, regarding (PTA-N1P2) threshold difference at 4000 Hz with absolute values Further analysis post-hoc test showed that the statistically significant differences were found between moderately severe and normal hearing, moderately severe and mild hearing loss, profound hearing loss and normal hearing, profound and mild, profound and moderate hearing loss in absolute values.

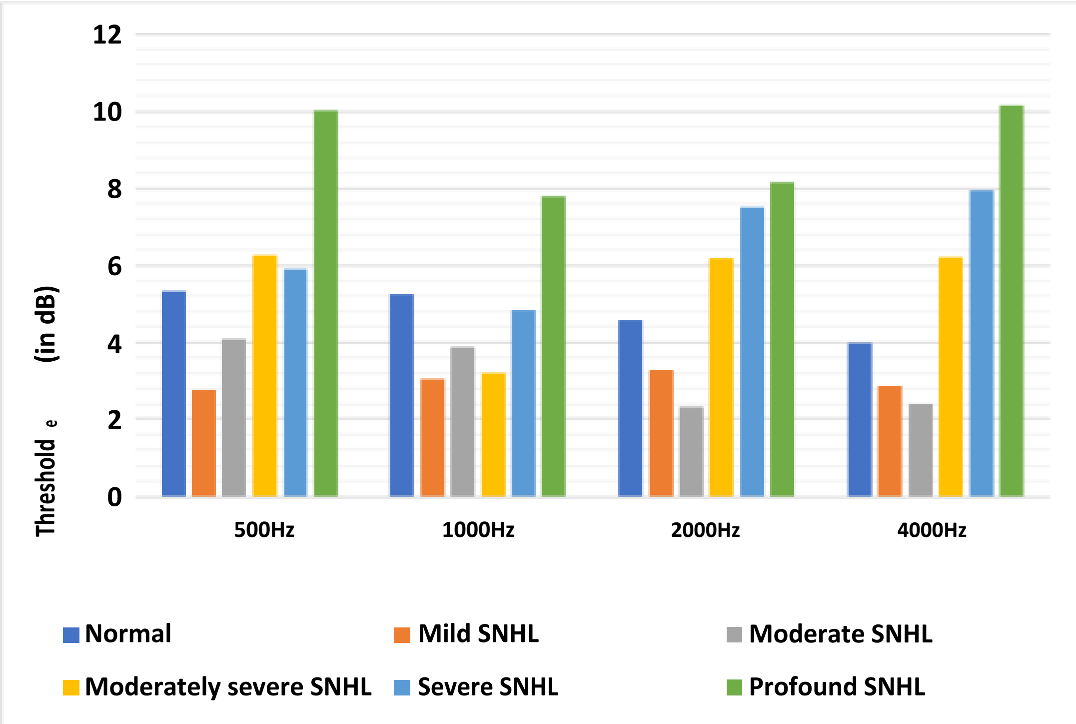

Fig (5): Frequency-Specific PTA-N1P2 threshold difference among the different hearing level ear groups

Table (10)
Comparison among frequencies regarding the PTA-N1P2 difference in Normal Hearing ears.

In Normal Hearing ears		No.	Mean	SD	Min	Max	F	Sig.
PTA-CAEP Difference *	500Hz	48	5.31	5.40	0.00	20	0.378	0.769
	1000Hz	44	5.23	6.47	0.00	20		
	2000Hz	36	4.58	6.25	0.00	20		
	4000Hz	24	3.96	4.16	0.00	20		
	Total	152	4.90	5.74	0.00	20		

*Negative sign removed to get the absolute values of the difference.

(table 10) showed no statistically significant difference in comparison among the different frequencies regarding the PTA-N1P2 difference in normal Hearing ears.

Table (11)
Comparison among frequencies regarding the PTA-N1P2 difference In Mild SNHL ears.

In Mild SNHL ears		No.	Mean	SD	Min	Max	F	Sig.
PTA-CAEP Difference *	500Hz	22	2.73	2.98	0	10	0.071	0.975
	1000Hz	23	3.04	4.19	0	15		
	2000Hz	23	3.26	4.42	0	15		
	4000Hz	14	2.86	4.69	0	15		
	Total	82	2.99	4.00	0	15		

*Negative sign removed to get the absolute values of the difference.

(Table 11) showed no statistically significant difference in comparison among the different frequencies regarding the PTA-N1P2 difference in mild SNHL.

Table (12)
Comparison among frequencies regarding the PTA-N1P2 difference In Moderate SNHL ears.

In Moderate SNHL ears		No.	Mean	SD	Min	Max	F	Sig.
PTA-CAEP Difference *	500Hz	27	4.07	5.20	0	15	0.673	0.572
	1000Hz	13	3.85	6.18	0	20		
	2000Hz	13	2.31	4.39	0	15		
	4000Hz	19	2.37	3.86	0	15		
	Total	72	3.26	4.90	0	20		

*Negative sign removed to get the absolute values of the difference.
(table 12) showed no statistically significant difference in comparison among the different frequencies regarding the PTA-N1P2 difference in moderate SNHL.

Table (13)
Comparison among frequencies regarding the PTA-N1P2 difference In Moderately Severe SNHL ears.

In Moderately Severe SNHL ears		N	Mean	SD	Min	Max	F	Sig.
PTA-CAEP Difference *	500Hz	24	6.25	6.80	0	25	1.569	0.202
	1000Hz	22	3.18	3.95	0	15		
	2000Hz	30	6.17	5.20	0	15		
	4000Hz	25	6.20	6.66	0	20		
	Total	101	5.54	5.83	0	25		

*Negative sign removed to get the absolute values of the difference.

(table 13) showed no statistically significant difference in comparison among the different frequencies regarding the PTA-N1P2 difference in moderately severe SNHL with absolute values.

Table (14)
Comparison among frequencies regarding the PTA-N1P2 difference In Severe SNHL ears.

In Severe SNHL ears		No.	Mean	SD	Min	Max	F	Sig.
PTA-CAEP Difference *	500Hz	17	5.88	4.41	0	15	1.397	0.249
	1000Hz	28	4.82	5.00	0	15		
	2000Hz	22	7.50	7.98	0	25		
	~~4000Hz~~	~~34~~	~~7.94~~	~~7.29~~	~~0~~	~~20~~		
	Total	101	6.63	6.52	0	25		

*Negative sign removed to get the absolute values of the difference.

(Table 14) showed no statistically significant difference in comparison among the different frequencies regarding the PTA-N1P2 difference in severe SNHL with absolute values.

Table (15)
Comparison among frequencies regarding the PTA-N1P2 difference In Profound SNHL ears.

In Profound SNHL ears		No.	Mean	SD	Min	Max	F	Sig.
PTA-CAEP Difference *	500Hz	11	10	10.49	0	30	0.66	0.579
	1000Hz	18	7.78	5.21	0	20		
	2000Hz	24	8.13	7.34	0	25		
	4000Hz	33	10.15	6.43	0	20		
	Total	86	9.07	7.05	0	30		

*Negative sign removed to get the absolute values of the difference.

(table 15) showed no statistically significant difference in comparison among the different frequencies regarding the PTA-N1P2 difference in profound SNHL.

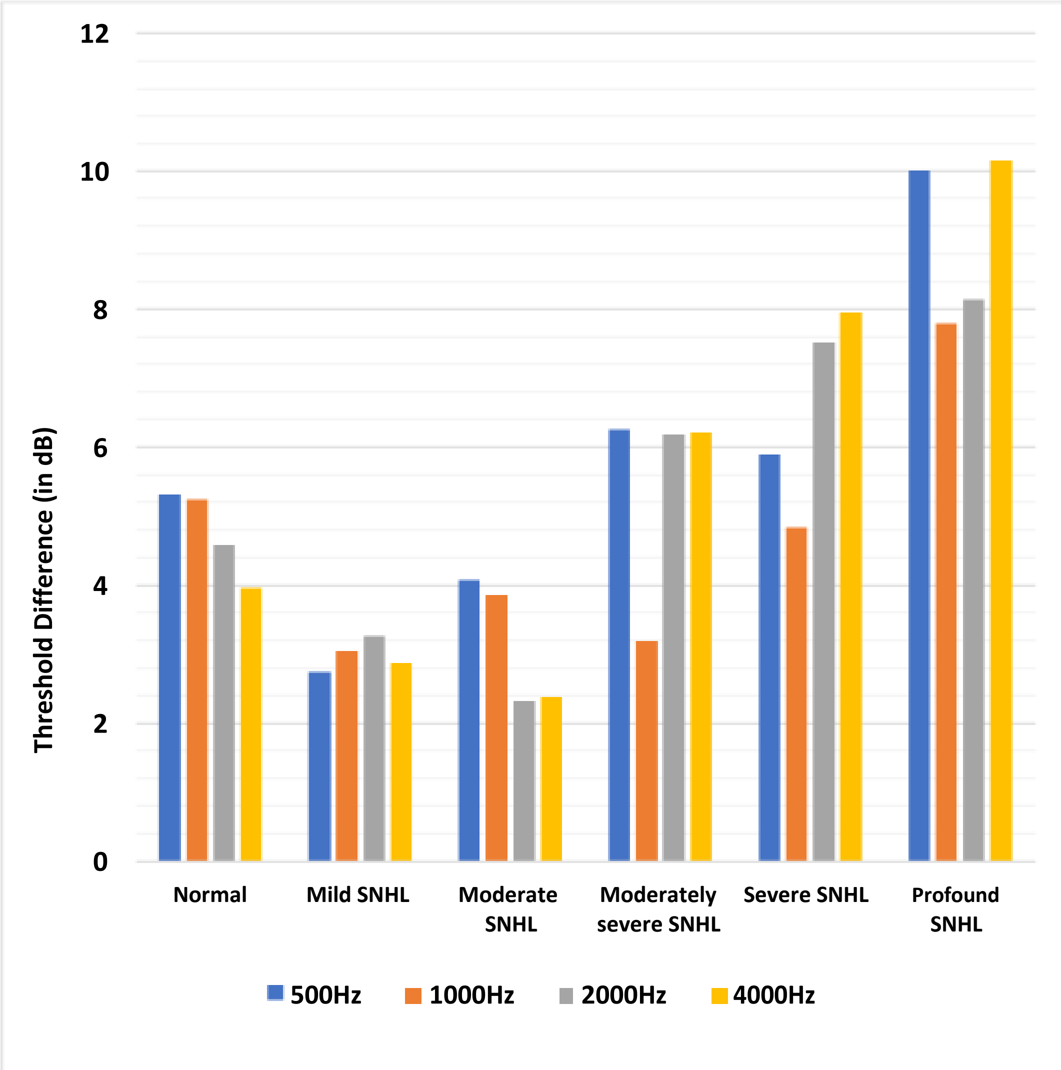

Fig (6): the PTA-N1P2 threshold difference at the different hearing level ear groups at the four different frequencies tested.

Table (16)
Correlation between PTA-N1P2 threshold difference with PTA threshold and between N1P2 threshold with PTA threshold at respective frequencies of the studied ears

			PTA-N1P2 Difference *	N1P2 threshold
PTA threshold	500 Hz	r	0.142	0.954
		P	0.084	0.000
	1000 Hz	r	0.013	0.966
		P	0.877	0.000
	2000 Hz	r	0.167	0.960
		P	0.042	0.000
	4000 Hz	R	0.329	0.965
		P	0.000	0.000

*Negative sign removed to get the absolute values of the difference.

Table (16) showed that there was no statistically significant correlation between the PTA threshold level and the PTA –N1P2 difference except that as the PTA threshold level was greater at **4000 Hz**, the PTA –N1P2 difference was greater. Pearson correlation coefficients were significant between PTA threshold level and N1P2 threshold level for all frequencies (table 16).

Discussion

The CAEP showed advantages over previous frequency specific evoked potentials in hearing threshold estimation in adults. This study aimed to correlate the hearing threshold level measured objectively by N1-P2 CAEP at multiple tonal frequencies to behavioural hearing threshold level at each respective frequency, in each degree of hearing loss. The measured N1P2 threshold did not statistically significant differ from the PTA threshold at the four tested frequencies in the different hearing degree groups of the study, except for statistically significant lower N1P2 threshold than PTA threshold in the profound hearing loss group at 1000 and 2000 Hz. And a statistically significant lower N1P2 threshold than PTA threshold in each of the Moderate, moderately severe, Severe and profound hearing loss groups but not in the Normal hearing or the Mild hearing loss groups at 4000 Hz.

Durante et al., (2016) and Yeung and Wong, (2007) found higher mean difference between CAEP and behavioural thresholds at 500, 1000, 2000 and 4000 Hz for normal hearing subjects in comparison to our study. The differences were 9.2, 9.1, 11.3, 12.1 respectively and the differences were 14.8, 14.5, 14.5, and 14.8 dB, at 500, 1000, 2000 and 4000 Hz respectively, (Durante et al., 2016) Yeung and Wong, (2007), which were smaller than our study values: 5.31, 5.23, 4.58 and 3.96 at 500, 1000, 2000 and 4000 Hz respectively. This may be explained by use of different method of electrophysiologic measurement. Durante et al., (2016) used the automatic cortical response threshold analysis equipment

Our study revealed that in the moderate SNHL ears group, our mean differences between CAEP and behavioral thresholds at 500, 1000, 2000 and 4000 Hz were 4.07, 3.85, 2.31, 2.37. In the moderately severe SNHL ears group, our mean differences between CAEP and behavioral thresholds at 500, 1000, 2000 and 4000 Hz was: 6.25, 3.18, 6.17, 6.20. In the severe SNHL ears group, our mean differences between CAEP and behavioral thresholds at 500, 1000, 2000 and 4000 Hz were: 5.88, 4.82, 7.50, 7.94.

Our results were in agreement to hearing-impaired subjects of Durante et al., (2016) at 2000 and 4000 Hz, but not in lower frequencies in which they obtained larger differences. However, we found that N1P2 was equally accurate in estimating the PTA threshold at all 4 tested frequencies in either the normal hearing ears, ears with mild, moderate, moderately severe, severe or profound SNHL, by comparison of the PTA-N1P2 difference among the different frequencies in each of the hearing degrees groups,

The CAEP electrophysiological method is effective in determining adult audiometric thresholds to within 10 dB of behavioural thresholds in normal hearing individuals, as well as those with hearing loss (Tomlin et al., 2006; Tsui, et al., 2002; Van Maanen and Stapells, 2005). CAEP threshold is generally 5 to 10 dB higher than the behavioural threshold (Lightfoot & Kennedy, 2006).

Van Dun et al., (2015) results showed that behavioral hearing thresholds could be estimated by subtracting on average 10 dB from the obtained cortical threshold. They stated that the use of a decision tree did not reduce test time, but there was significantly less variation across participants in the number of recordings needed to determine a threshold. They concluded that a combination of objective cortical-response detection with a decision tree presents a promising first approach toward automated hearing-threshold estimation.

Cone-Wesson et al., (2002); Tsui et al., (2002); Yeung and Wong, (2007) found that hearing thresholds are more accurately predicted when the degree of hearing loss increases and as test frequency increases. In partial agreement with previous studies comparing differences among the hearing degrees groups of the study that in the current study there was a statistically significant smaller PTA-N1P2 threshold difference in moderately severe than the Normal and profound hearing loss groups, and significant smaller PTA-N1P2) threshold difference in mild than profound hearing loss group, at 1000 Hz. Moreover, there was a statistically significant higher PTA-N1P2 threshold difference in the moderately severe than the Normal and mild hearing loss groups at 4000 Hz. There was a statistically significant higher PTA-N1P2 threshold difference in the profound than the Normal, mild and moderate hearing loss groups at 4000 Hz. N1P2 was equally accurate in estimating the PTA threshold at all hearing degrees however, as the PTA threshold level was greater at 4000 Hz, the PTA –N1P2 difference was greater.

However, regarding (PTA-N1P2) threshold difference, there were no statistically significant differences among the hearing degree groups of the study, at 500 Hz and at 2000 Hz. And PTA threshold level and N1P2 threshold level were highly correlated at all frequencies.

In agreement with the current study, Bott et al., (2020) explored the feasibility of cortical automatic threshold estimation (CATE), a fully automated late auditory evoked potential test, as an alternative to pure-tone audiometry for hearing threshold estimation for adults with dementia living in aged care. They found that on average, cortical thresholds were 7 dB higher than behavioural thresholds (SD ¼ 12 dB) in adults with hearing impairment. For normal-hearing adults the sensitivity of CATE was found to be 96% with a 95% specificity for stimuli presented above 20 dB HL, demonstrating its overall validity for hearing threshold estimation.

In contrast to -Wesson et al., (2002); Tsui et al., (2002); Yeung and Wong, (2007), we found larger differences in the profound SNHL ears group, compared to less severe degrees of hearing loss. Our mean differences between CAEP and behavioral thresholds in the profound SNHL ears group, at 500, 1000, 2000 and 4000 Hz were: 10.00, 7.78, 8.13, 10.15. In the mild SNHL ears group, our mean differences between CAEP and behavioural thresholds at 500, 1000, 2000 and 4000 Hz were: 2.73, 3.04, 3.26, 2.86. Differences may be explained by use of different method of CAEP measurement. However, the N1P1 CAEP remains a valuable objective tool to assess the hearing threshold level in adults who can not provide a reliable behavioural threshold.

Conclusions

The measured N1P2 threshold in this study was lower and correlated well within less than 10 dB to the PTA threshold. N1P2 has excellent frequency specificity and is equally accurate in estimating the PTA threshold at all 4 tested frequencies in any degree of hearing: either the normal hearing ears, or ears with mild, moderate, moderately severe, severe or profound SNHL. Comparing differences among the hearing degree groups, N1P2 was equally accurate in estimating the PTA threshold at all hearing degrees at 500 Hz and at 2000 Hz, while at 1000 Hz and 4000 Hz, the difference was smaller at less severe degrees of hearing loss.

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