Scientific Research Publishing

Journal of Biosciences and Medicines, 2025, 13(2), 480-490
https://www.scirp.org/journal/jbm
ISSN Online: 2327-509X
ISSN Print: 2327-5081

Relationship between Cortical Auditory Evoked Potential (CAEP) Responses and Behavioral Thresholds in Children with Sensorineural Hearing Loss

Hee Yen Tan[1], Wendi Shi[2], Yonghua Wang[2]

[1]International Education College, Zhejiang Chinese Medical University, Hangzhou, China
[2]Hangzhou Ren-Ai Hearing Rehabilitation Center for Deaf Children, Hangzhou, China
Email: tanheeyen@gmail.com

How to cite this paper: Tan, H.Y., Shi, W.D. and Wang, Y.H. (2025) Relationship between Cortical Auditory Evoked Potential (CAEP) Responses and Behavioral Thresholds in Children with Sensorineural Hearing Loss. *Journal of Biosciences and Medicines*, **13**, 480-490.
https://doi.org/10.4236/jbm.2025.132036

Received: January 12, 2025
Accepted: February 24, 2025
Published: February 27, 2025

Copyright © 2025 by author(s) and Scientific Research Publishing Inc.
This work is licensed under the Creative Commons Attribution International License (CC BY 4.0).
http://creativecommons.org/licenses/by/4.0/
Open Access

Abstract

Objective: To study the relationship between cortical auditory evoked potential (CAEP) thresholds and behavioral thresholds in pediatric populations with sensorineural hearing loss (SNHL). **Methods:** Fifteen children (mean age 6.8 years) with bilateral SNHL underwent behavioral pure-tone audiometry and CAEP testing at 0.5, 1, 2, and 4 kHz. CAEP thresholds were determined using tone bursts, and correlations between CAEP and pure-tone thresholds were analyzed using Pearson correlation and t-tests. **Results:** A strong positive correlation was observed between P1 thresholds and behavioral thresholds across all test frequencies: 0.5 kHz ($r = 0.765$, $p < 0.001$), 1 kHz ($r = 0.891$, $p < 0.001$), 2 kHz ($r = 0.871$, $p < 0.001$), and 4 kHz ($r = 0.922$, $p < 0.001$). Correction values between P1 and behavioral thresholds were established: 0.5 kHz (11 dB HL), 1 kHz (9 dB HL), 2 kHz (12 dB HL), and 4 kHz (13 dB HL). Mean P1 latencies ranged from 145.19 ms to 149.06 ms, and N1 latencies ranged from 212.34 ms to 232.26 ms across frequencies. **Conclusion:** The strong correlation between P1 and behavioral thresholds demonstrates the reliability of CAEP testing for estimating auditory thresholds in children. These findings support the use of CAEP testing as a reliable objective tool for threshold estimation, particularly in cases where behavioral responses cannot be reliably obtained. When adjusted with frequency-specific correction values, CAEP testing provides a reliable method for assessing hearing thresholds in pediatric populations.

Keywords

Cortical Auditory Evoked Potentials, Behavioral Thresholds, Sensorineural

Hearing Loss, Hearing Threshold Estimation

1. Introduction

Over 1.5 billion people worldwide experience hearing impairment, accounting for approximately 20% of the global population [1]. Unaddressed hearing loss significantly impacts quality of life, causing challenges in communication, delayed speech, language, and cognitive development. These deficits often lead to poorer psychosocial well-being, limited educational achievement, vocational challenges, and an increased risk of unemployment [1]. Early diagnosis and intervention are crucial, particularly for children, as timely management can enable developmental milestones comparable to peers with normal hearing [2].

In China, newborn hearing screening coverage increased from 29.9% in 2008 to 86.5% in 2016 [3]. However, interprovincial disparities persist, and children in regions without comprehensive screening programs may undergo hearing assessments only later in life. Pure-tone audiometry, a behavioral testing for determining hearing thresholds, is considered the gold standard for identifying the type, degree, and configuration of hearing loss [4]. It guides audiologists and healthcare professionals in diagnosis and treatment planning. The reliability of hearing threshold measurements in behavioral testing is highly dependent on the child's cognitive, linguistic, and motor development. Children with additional disabilities often struggle to reliably participate in behavioral testing, thus emphasizing the necessity for objective testing methods.

Electrophysiological tests, including Auditory Brainstem Response (ABR), Auditory Steady-State Response (ASSR), and Cortical Auditory Evoked Potential (CAEP), are capable of estimating hearing thresholds. However, the utilization of CAEP for threshold estimation has been limited, primarily due to the dominance of ABR and ASSR as the prevailing diagnostic techniques in the field. CAEPs represent obligatory neural responses, reflecting the cumulative activity of the auditory cortex. These potentials are elicited by the onset, change, or offset of a sound, and occur regardless of whether the individual is actively attending to the auditory input [5]. The three distinct components of the mature supra-threshold CAEP, labeled as P1, N1, and P2, reflect sequential stages of auditory cortical processing [6]. Following the stimulus onset, the P1 component, a positive peak, typically occurs around 50 - 70 milliseconds (ms). After the P1 component, the N1 component, a negative trough, is observed at 100 - 130 ms. After the N1 component, the P2 component, a positive peak, appears at 200 - 250 ms [6]. These components reflect the auditory pathway functionality and cortical processing of sound stimuli.

The morphology of CAEP is influenced by several factors, including age, arousal state, attention, and the specific characteristics and parameters of the auditory stimuli presented. The P1 component can be reliably elicited in infants from birth, whereas the N1 component becomes reliably evoked only by approximately seven years of age [7]. The mature waveform morphology is primarily characterized by N1, which is subsequently followed by P2 [8]. The N1-P2 response reaches full maturity in predicting auditory sensitivity only during late adolescence [8]. In pediatric populations, P1 emerges as the robust and predominant component of the CAEP, further serving to indicate the maturation of central auditory processes [9]. As age increases, the auditory system matures in children, the N1 and P2 components progressively emerge from the dominant P1 component [7]. Therefore, the P1 component is commonly employed in estimating hearing thresholds in children.

Previous studies have demonstrated the utility of CAEP testing in clinical settings for estimating hearing thresholds. Research in adults with normal hearing and bilateral sensorineural hearing loss (SNHL) has shown a strong correlation between thresholds obtained from the N1-P2 response of CAEP testing and pure-tone audiometry at four frequencies (0.5 k, 1 k, 2 k, and 4 kHz), which are integral for calculating the pure-tone average [10]-[12]. Similarly, research in neonates and infants has highlighted the potential of the P1 component of CAEP to provide insights into auditory pathway development and to serve as an accurate predictor of hearing thresholds. Cone and Whitaker (2013) demonstrated the feasibility and precision of CAEP threshold estimation in infants with normal hearing aged 4 - 12 months [13]. Oliveira *et al.* (2019) further validated the accuracy of CAEP testing in accurately estimating hearing thresholds at the aforementioned frequencies in normal hearing neonates up to 28 days old [14]. He *et al.* (2013) further expanded the application of CAEP testing to children with Auditory Neuropathy Spectrum Disorder (ANSD), demonstrating its potential for estimating hearing thresholds in five children aged 6 to 10 years with the disorder [15]. Cardon and Sharma (2021) further reinforced these findings, demonstrating that CAEP testing reliably estimates hearing thresholds across diverse auditory conditions, including normal hearing, SNHL, and ANSD, in both adults and children [16].

This study focuses on CAEP rather than other objective tests like ABR and ASSR for several reasons. Unlike ABR, which assesses neural responses in the brainstem, CAEP provides insights into higher-order auditory processing up to the cortical level [17]. This makes CAEP particularly valuable for evaluating the entire auditory pathway and its functional integrity. Moreover, ABR and ASSR have limitations in pediatric populations, as they require the subject to be asleep or still for prolonged periods [16]. This poses significant challenges, especially for older children who are more likely to be awake and active compared to infants. General anesthesia, often used to facilitate ABR and ASSR testing, carries risks and may be unsuitable for children with certain health conditions. In contrast, CAEP testing can be performed while children are awake and alert, making it a more feasible option for populations that may not benefit from other electrophysiological tests.

Studies have shown that CAEPs can reliably estimate hearing thresholds in infants, younger children, and adults, with good correlation to behavioral audiograms.

Despite the extensive validation of CAEP testing in threshold estimation, its application in older children with SNHL has not been widely explored. The present study aims to address this gap by investigating the correlation between CAEP thresholds and behavioral thresholds in children aged 4 to 12 years with SNHL across 0.5, 1, 2, and 4 kHz. This study focuses on the clinical utility of CAEP in this age group and its potential to expand diagnostic options for populations where behavioral or other electrophysiological methods may be challenging to implement. The findings could facilitate broader adoption of CAEP testing in clinical practice, providing a reliable alternative for assessing hearing thresholds in pediatric populations with SNHL.

2. Methods

2.1. Subjects

Fifteen children (9 males and 6 females), comprising 28 ears, were recruited for this study. The mean age was 6.8 ± 2.4 years (range 4 - 11 years). Inclusion criteria for the study were as follows: 1) Children with a confirmed diagnosis of bilateral SNHL; 2) The ability to reliably perform pure-tone audiometry, defined as consistent responses to stimuli during testing. Exclusion criteria included: 1) The presence of conductive or mixed hearing loss, as determined by air-bone gap thresholds exceeding 10 dB HL at any frequency; 2) Abnormal tympanometry results indicative of middle ear pathology such as Type B or C tympanograms; 3) Any diagnosed cognitive or developmental disorders that may potentially interfere the outcomes of behavioral testing. The pure-tone average for the tested ears was categorized as follows: 2 ears with 26 - 40 dB HL, 8 ears with 41 - 60 dB HL, 12 ears with 61 - 80 dB HL, and 6 ears with ≥81 dB HL.

2.2. Behavioral Testing

Air conduction thresholds were obtained using the GSI Audiostar Pro audiometer and sound stimuli were delivered through ER-3A insert earphones. Pure-tone audiometry was conducted in a soundproof room with background noise levels below 35 dB A. The test frequencies were 0.5, 1, 2, and 4 kHz, and air conduction thresholds for both ears at each frequency were obtained following the Hughson and Westlake procedure. Children responded to the sound stimuli either by raising their hands or via conditioned play audiometry.

2.3 Measurement of Cortical Auditory Evoked Potentials

CAEP testing was conducted in a soundproof chamber with background noise levels below 35 dBA. Unaided air conduction CAEPs were recorded using the Neuro-Audio system. Before placing the disposable electrodes, the skin was cleaned with cotton wool to remove oil or debris. Electrodes were positioned for recording: the active electrode was placed on the vertex, the two reference electrodes were placed on the mastoid processes, and the ground electrode was placed on the low forehead. The electrode impedance was maintained below 3 kΩ. Sound was delivered using ER-3C insert earphones. The test stimuli were tone bursts, delivered at a stimulation rate of 1 per second, with a window time of 500 ms. The artifact rejection with amplitude criterion at ± 100 µV. The average number of sweeps was 50 to 100, and the bandpass filter was set at 0.3 to 30 Hz. The test frequencies were 0.5, 1, 2, and 4 kHz. All children were instructed to sit comfortably, accompanied by a parent during the testing process. They were required to remain awake and quiet, with silent videos played to maintain their alertness. To prevent fatigue, a 5-minute break was taken after measuring the P1 threshold for every two frequencies. CAEP thresholds were interpreted and identified by experienced audiologists. When a distinct P1 peak was observed, the sound intensity was decreased by 10 dB. It was then increased by 10 dB, if the P1 was not elicited. The threshold was then determined through stepwise adjustments of 5 dB increments and decrements. Each intensity level is tested twice until the threshold was approached.

2.4. Statistical Analysis

The obtained data was statistically analyzed using SPSS 27.0 software. A Pearson correlation test was employed to analyze the relationship between the P1 thresholds and behavioral thresholds across the test frequencies. The difference between the P1 threshold and the corresponding behavioral threshold at each frequency was calculated using paired sample t-test. The significance level was set at $p < 0.05$.

3. Results

3.1. Relationship between P1 Thresholds and Behavioral Thresholds

Figure 1 shows the CAEP response waveforms at 1 kHz recorded from a subject. Pearson correlation analysis revealed a strong positive correlation between the P1 thresholds and the behavioral thresholds across the four test frequencies: 0.5 kHz ($r = 0.765$, $p < 0.001$), 1 kHz ($r = 0.891$, $p < 0.001$), 2 kHz ($r = 0.871$, $p < 0.001$), and 4 kHz ($r = 0.922$, $p < 0.001$). Scatter plots illustrating these relationships are presented in Figure 2.

3.2. Differences between P1 Thresholds and Behavioral Thresholds

Statistically significant differences were observed between the P1 thresholds and the behavioral thresholds at frequencies of 0.5, 1, 2, and 4 kHz, with all results indicating $P < 0.001$, as summarized in Table 1. The mean latency of P1 and N1 at threshold across the four test frequencies is shown in Table 2.

4. Discussion

Although extensive research has explored the use of CAEP testing for threshold estimation in infants, young children, and adults, its application in older children with SNHL remains under explored. This study investigated the relationship between CAEP P1 thresholds and behavioral thresholds in children aged 4 to 12 years with SNHL, focusing on the thresholds at four specific frequencies for pure-tone

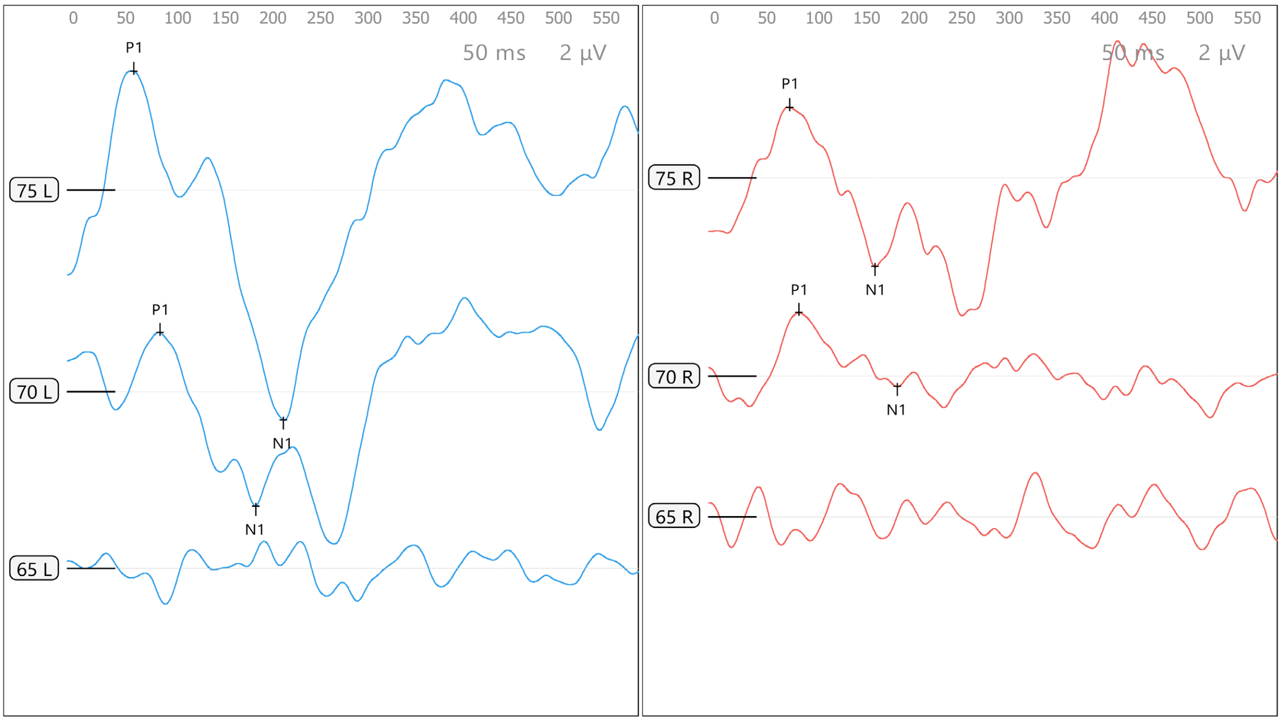

Figure 1. CAEP waveforms at 1 kHz recorded from a subject. The P1 and N1 components are clearly visible at higher intensities, with a progressive reduction in amplitude and increased latency as stimulus intensity decreases. The thresholds for both ears are 70 dB HL.

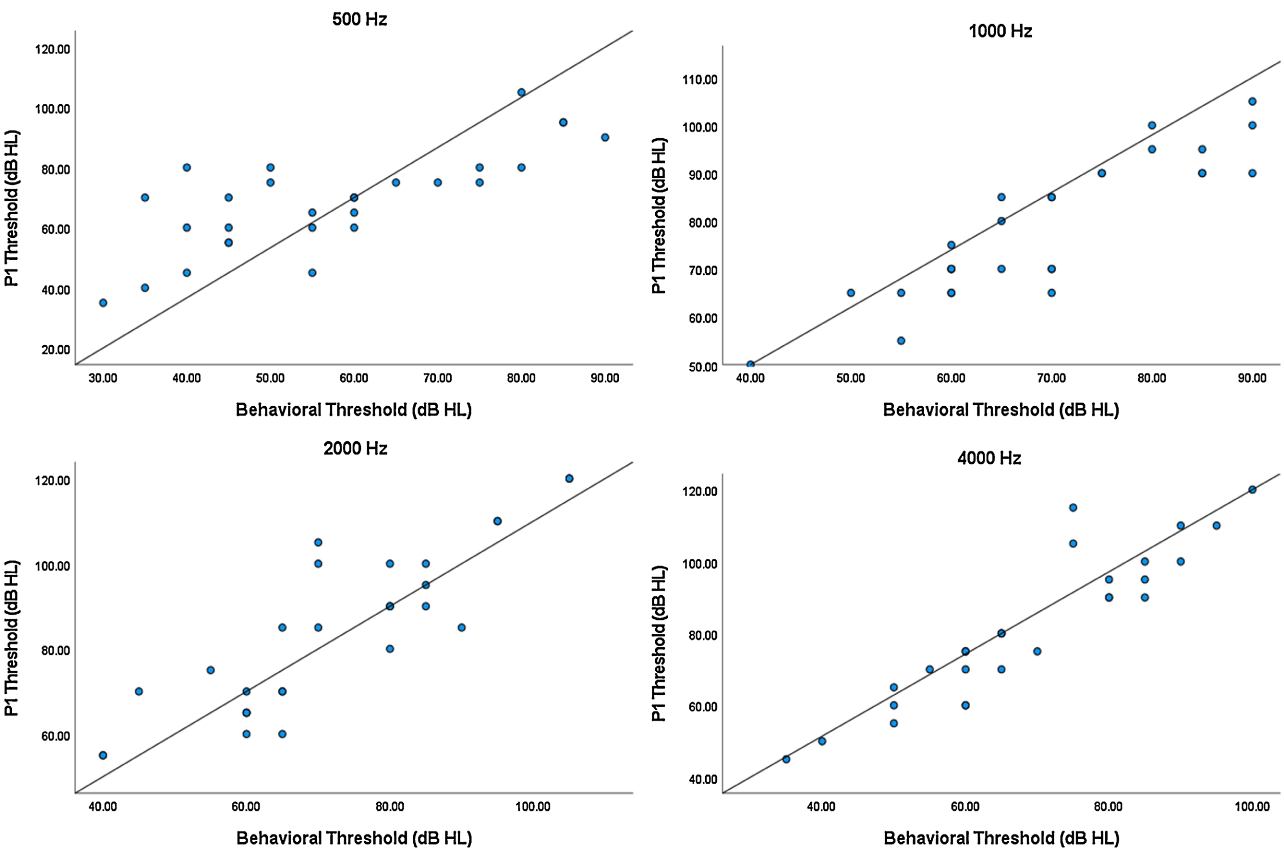

Figure 2. Scatter plots between P1 threshold and behavioral threshold across four frequencies.

Table 1. The difference between P1 thresholds and behavioral thresholds across four frequencies (n = 28).

Frequency (kHz)	P1 threshold (dB HL)	Behavioral threshold (dB HL)	Difference	95% Confidence Interval		t value	p value
				Lower limit	Upper limit		
0.5	68.93 ± 16.80	57.50 ± 17.08	11.43 ± 11.62	6.92	15.93	5.206	<0.001
1	78.75 ± 14.51	69.29 ± 12.96	9.46 ± 6.57	6.92	12.01	7.618	<0.001
2	83.75 ± 19.42	71.96 ± 17.55	11.79 ± 9.55	8.08	15.49	6.533	<0.001
4	81.79 ± 20.42	68.93 ± 16.63	12.86 ± 8.21	9.67	16.04	8.283	<0.001

Table 2. The average latencies of P1 and N1 thresholds across four frequencies (n = 28).

Frequency (kHz)	Latency (ms)	
	P1	N1
0.5	148.07 ± 33.26	232.26 ± 41.46
1	148.31 ± 30.50	229.23 ± 35.92
2	145.19 ± 28.89	212.34 ± 34.96
4	149.06 ± 31.92	214.31 ± 34.43

average calculations. The findings revealed a strong, statistically significant positive correlation between CAEP P1 thresholds and behavioral thresholds across the tested frequencies of 0.5, 1, 2, and 4 kHz. Furthermore, the study compared P1 thresholds with behavioral thresholds and established correction values at these frequencies: 0.5 kHz (11 dB HL), 1 kHz (9 dB HL), 2 kHz (12 dB HL), and 4 kHz (13 dB HL).

The results of this study are consistent with previous research, highlighting the reliability of CAEP thresholds in estimating hearing thresholds in older children. The findings demonstrate a strong relationship between CAEP thresholds and behavioral thresholds across frequencies of 0.5, 1, 2, and 4 kHz, aligning with findings from prior studies [10]-[12]. Additionally, the P1 component, which has been identified as a reliable predictor of hearing thresholds in infants and young children, has been shown to be equally effective in estimating hearing thresholds in older children [13]-[16].

To clinically apply CAEP testing for threshold estimation, it is important to investigate and address the discrepancy between CAEP and behavioral thresholds. Correcting these differences is crucial to ensure the accuracy and reliability of CAEP as a tool for estimating hearing thresholds. In this study, the thresholds derived from CAEP testing across the tested frequencies were generally higher than those obtained through behavioral testing, findings that align with previous studies [10] [12] [16]. After subtracting the correction values, P1 thresholds can reliably estimate hearing thresholds. These correction values should be clearly stated in clinical reports [6].

The correction values identified in this study (11, 9, 12, and 13 dB HL for the tested frequencies) are consistent with previous findings. Wong *et al.* (2008)

reported a mean difference of approximately 15 dB HL when comparing CAEP thresholds elicited by tone bursts to pure-tone thresholds [12]. Similarly, Cardon and Sharma (2021) found that CAEP thresholds using a 1 kHz pure-tone and the speech stimulus /ba/ were within 10 dB HL of pure-tone thresholds in normal-hearing adults and children [16]. Zhang *et al.* (2023) noted that the discrepancy between CAEP and pure-tone thresholds is greater in adults with normal hearing compared to those with SNHL, highlighting the need for distinct correction values tailored to individuals with normal hearing and those with SNHL [10].

Both tone-burst and speech stimuli are effective in eliciting CAEPs. Research comparing tone bursts and speech stimuli in CAEP testing further supports that both tone bursts and speech stimuli are appropriate for recording CAEPs in children [18]. As compared to tone-burst stimuli, larger P1 amplitudes were found for CAEP evoked by speech stimuli and speech stimuli containing multiple frequencies are more natural [18]. However, tone bursts offer a distinct advantage by facilitating frequency-specific evaluation of auditory sensitivity, thereby enhancing the clinical applicability of CAEP testing in threshold estimation. These findings emphasize the reliability of tone bursts as stimuli for estimating hearing thresholds in older children with SNHL.

In pediatric populations, the P1 component is the prominent and consistently observed component of CAEP [19]. Originating from synaptic activity in the primary auditory cortex, thalamo-cortical projections, and intracortical recurrent activity, the P1 component provides critical insights into early auditory cortical processing [19]. In contrast to adults, who primarily utilize the N1-P2 complex for threshold measurements, children rely on the P1 component due to developmental differences. In infants and young children, the N1 component overlaps the P1 component, making it harder to distinguish. As individuals age, the N1 component becomes more distinct, demonstrating longer latencies [20]. This developmental progression underscores the unique trajectory of auditory system maturation in children and highlights the importance of utilizing age appropriate biomarkers for precise evaluation of hearing thresholds and monitoring maturation processes.

P1 latency is highly age-dependent, thus serving as a valuable biomarker for assessing central auditory development in children. Infants and young children typically exhibit P1 peak latency ranging from 100 to 300 ms [19]. As the auditory system matures, P1 latency and amplitude gradually decrease, reaching approximately 60 ms by late adolescence [19]. This reduction in latency reflects cortical maturation, including enhanced synaptic connectivity, improved myelination, and shortened refractory periods [20]. The findings of this study revealed prolonged P1 and N1 latencies compared to those of normal-hearing children. Generally, P1 latency in normal hearing children ranges between 85 - 95 ms and gradually decreases with age, ultimately reaching adult levels of approximately 40 - 60 ms [20] [21]. Following the P1 peak, the N1 component emerges as a negative trough, with latencies of 100 - 150 ms observed in children aged 5 - 6 years [21].

As development progresses, the N1 component becomes more prominent, stabilizing around 100 ms in adults. The reduction in P1 latency with age is thought to reflect the maturation of auditory pathways, marked by more efficient synaptic transmission and improved neural connectivity.

CAEP is considered a more reliable method for hearing threshold estimation compared to ABR and ASSR. Unlike ABR, which captures neural activity at the early stages of the auditory pathway within the brainstem, CAEP measures neural responses at the cortical level. This cortical assessment enables CAEP to provide valuable insights into auditory processing at advanced stages of the auditory pathway, including the evaluation of speech perception [22]. Additionally, studies have highlighted the advantages of CAEP over ASSR, particularly in estimating behavioral hearing thresholds. These advantages are most evident at lower frequencies and in cases of severe hearing loss, where the CAEP waveform, particularly the N1-P2 component, demonstrates higher reliability [23].

The findings of this study have significant implications for clinical pediatric hearing assessment in audiology. Obtaining behavioral thresholds can be challenging in children who are incapable of providing reliable responses, such as those with multiple disabilities. In such cases, the application of objective measures, such as CAEP testing, is essential in estimating hearing thresholds and guiding early intervention and rehabilitation planning. This study validates the clinical utility of CAEP testing in estimating hearing thresholds in older children. To further validate these findings, future studies should include larger sample sizes of pediatric population with SNHL, and further divided into different age groups, in order to establish reference values for different age ranges. Establishing age-specific reference values will enhance the clinical applicability of CAEP testing and provide a framework for its integration into audiological evaluations.

5. Conclusion

This study demonstrated a strong correlation between CAEP testing using tone bursts as stimuli and behavioral audiometry at the four frequencies used to calculate the pure-tone average in children aged 4 - 12. The P1 component of the CAEP serves as a biomarker that is readily recordable and non-invasive, eliminating the need for anesthesia. As a result, CAEP testing can serve as a reliable objective method for estimating hearing thresholds in older children for whom accurate behavioral thresholds are difficult to obtain. Notably, for children who do not benefit from ABR or ASSR testing, CAEP threshold estimation offers a viable alternative. This is particularly advantageous in pediatric populations that are challenging to assess, such as children with multiple disabilities. By enabling the estimation of hearing thresholds, CAEP testing facilitates earlier diagnostic and rehabilitative interventions, ultimately improving the outcomes of auditory management.

Acknowledgements

I extend my sincere gratitude to my supervisors, Professor Wang Yonghua and

Shi Wendi, for their invaluable guidance, insightful ideas, and consistent support throughout this research. Their expertise and constructive feedback have been crucial in shaping this work. I also wish to thank Liyang and Zha Shihua for their meticulous efforts in conducting the tests and ensuring the reliability of the data collection process. Their technical expertise has been indispensable to the success of this study. Finally, I acknowledge the contributions of all individuals in Huier's clinic who have supported this research, directly or indirectly.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

[1] World Health Organization (2021, March 3) World Report on Hearing. Geneva. https://www.who.int/publications-detail-redirect/9789240020481

[2] Stika, C.J., Eisenberg, L.S., Johnson, K.C., Henning, S.C., Colson, B.G., Ganguly, D.H., *et al.* (2015) Developmental Outcomes of Early-Identified Children Who Are Hard of Hearing at 12 to 18months of Age. *Early Human Development*, **91**, 47-55. https://doi.org/10.1016/j.earlhumdev.2014.11.005

[3] Yuan, X., Deng, K., Zhu, J., Xiang, L., Yao, Y., Li, Q., *et al.* (2020) Newborn Hearing Screening Coverage and Detection Rates of Hearing Impairment across China from 2008-2016. *BMC Pediatrics*, **20**, Article No. 360. https://doi.org/10.1186/s12887-020-02257-9

[4] Musiek, F.E., Shinn, J., Chermak, G.D. and Bamiou, D. (2017) Perspectives on the Pure-Tone Audiogram. *Journal of the American Academy of Audiology*, **28**, 655-671. https://doi.org/10.3766/jaaa.16061

[5] Van Dun, B., Dillon, H. and Seeto, M. (2015) Estimating Hearing Thresholds in Hearing-Impaired Adults through Objective Detection of Cortical Auditory Evoked Potentials. *Journal of the American Academy of Audiology*, **26**, 370-383. https://doi.org/10.3766/jaaa.26.4.5

[6] British Society of Audiology (2022) Recommended Procedure: Cortical Auditory Evoked Potential (CAEP) Testing. https://www.thebsa.org.uk/wp-content/uploads/2023/10/OD104-40-BSA-Recommended-Procedure-CAEP.pdf

[7] Sharma, A., Glick, H., Deeves, E. and Duncan, E. (2015). The P1 Biomarker for assessing Cortical Maturation in Pediatric Hearing Loss: A Review. *Otorinolaringologia*, **65**, 103-114. https://pubmed.ncbi.nlm.nih.gov/27688594/

[8] Lightfoot, G. (2016) Summary of the N1-P2 Cortical Auditory Evoked Potential to Estimate the Auditory Threshold in Adults. *Seminars in Hearing*, **37**, 1-8. https://doi.org/10.1055/s-0035-1570334

[9] Sharma, A. and Dorman, M.F. (2006) Central Auditory Development in Children with Cochlear Implants: Clinical Implications. In: *Cochlear and Brainstem Implants*, Møller, A.R., Ed., Karger, 66-88. https://doi.org/10.1159/000094646

[10] Zhang, Y., Wang, S., Liu, H., Zhang, J., Chen, J. and Mo, L. (2023) Hearing Assessment by Complex Wave N1-P2 of Cortical Auditory Evoked Potentials. *Journal of Audiology and Speech Pathology*, **31**, 527-530. https://link.cnki.net/urlid/42.1391.r.20230327.1535.002

[11] Durante, A.S., Wieselberg, M.B., Roque, N., Carvalho, S., Pucci, B., Gudayol, N., *et al*. (2017) Assessment of Hearing Threshold in Adults with Hearing Loss Using an Automated System of Cortical Auditory Evoked Potential Detection. *Brazilian Journal of Otorhinolaryngology*, **83**, 147-154. https://doi.org/10.1016/j.bjorl.2016.02.016

[12] Wong, L.L.N., Cheung, C. and Wong, E.C.M. (2008) Comparison of Hearing Thresholds Obtained Using Pure-Tone Behavioral Audiometry, the Cantonese Hearing in Noise Test (CHINT) and Cortical Evoked Response Audiometry. *Acta Oto-Laryngologica*, **128**, 654-660. https://doi.org/10.1080/00016480701642189

[13] Cone, B. and Whitaker, R. (2013) Dynamics of Infant Cortical Auditory Evoked Potentials (CAEPs) for Tone and Speech Tokens. *International Journal of Pediatric Otorhinolaryngology*, **77**, 1162-1173. https://doi.org/10.1016/j.ijporl.2013.04.030

[14] Oliveira, L.S., Didoné, D.D. and Durante, A.S. (2019) Automated Cortical Auditory Evoked Potentials Threshold Estimation in Neonates. *Brazilian Journal of Otorhinolaryngology*, **85**, 206-212. https://doi.org/10.1016/j.bjorl.2018.01.001

[15] He, S., Teagle, H.F.B., Roush, P., Grose, J.H. and Buchman, C.A. (2013) Objective Hearing Threshold Estimation in Children with Auditory Neuropathy Spectrum Disorder. *The Laryngoscope*, **123**, 2859-2861. https://doi.org/10.1002/lary.24137

[16] Cardon, G. and Sharma, A. (2021) Cortical Neurophysiologic Correlates of Auditory Threshold in Adults and Children with Normal Hearing and Auditory Neuropathy Spectrum Disorder. *American Journal of Audiology*, **30**, 28-42. https://doi.org/10.1044/2020_aja-20-00062

[17] Liégeois-Chauvel, C., Musolino, A., Badier, J.M., Marquis, P. and Chauvel, P. (1994) Evoked Potentials Recorded from the Auditory Cortex in Man: Evaluation and Topography of the Middle Latency Components. *Electroencephalography and Clinical Neurophysiology/Evoked Potentials Section*, **92**, 204-214. https://doi.org/10.1016/0168-5597(94)90064-7

[18] Mukari, S.Z.S., Umat, C., Chan, S.C., Ali, A., Maamor, N. and Zakaria, M.N. (2020) Effects of Age and Type of Stimulus on the Cortical Auditory Evoked Potential in Healthy Malaysian Children. *Journal of Audiology and Otology*, **24**, 35-39. https://doi.org/10.7874/jao.2019.00262

[19] Campbell, J., Cardon, G. and Sharma, A. (2011) Clinical Application of the P1 Cortical Auditory Evoked Potential Biomarker in Children with Sensorineural Hearing Loss and Auditory Neuropathy Spectrum Disorder. *Seminars in Hearing*, **32**, 147-155. https://doi.org/10.1055/s-0031-1277236

[20] Eggermont, J.J. and Ponton, C.W. (2003) Auditory-Evoked Potential Studies of Cortical Maturation in Normal Hearing and Implanted Children: Correlations with Changes in Structure and Speech Perception. *Acta Oto-Laryngologica*, **123**, 249-252. https://doi.org/10.1080/0036554021000028098

[21] Xiong, S., Jiang, L., Wang, Y., Pan, T. and Ma, F. (2022) The Role of the P1 Latency in Auditory and Speech Performance Evaluation in Cochlear Implanted Children. *Neural Plasticity*, **2022**, 1-10. https://doi.org/10.1155/2022/6894794

[22] Li, Y. L., Liu, X. H., Fu, X. X. and Qi, B. E. (2017). Characterization of Cortical Audi-Tory Evoked Potential (P1-N1-P2) in Normal Hearing Young Adults. *Journal of Clinical Otorhinolaryngology Head and Neck Surgery*, **31**, 262-266. https://doi.org/10.13201/j.issn.1001-1781.2017.04.005

[23] Dabbous, A., El-Shennawy, A., Hamdy, M. and Nabieh, S. (2020) Comparison of N1P2 Cortical Auditory Evoked Potential and Narrow-Band Chirp Auditory Steady State Potential in Hearing Threshold Detection in Adults. *Journal of Hearing Science*, **10**, 48-68. https://doi.org/10.17430/jhs.2020.10.4.6