ORIGINAL ARTICLE

Analysis of Auditory Brainstem Response Test Time Using Narrow Band Level Specific CE-Chirp and Tone Burst in Infants

Amnah Mohamad Noor[1], Ahmad Aidil Arafat Dzulkarnain,[1,2*], Saiful Adli Jamaluddin[1], and Sarah Rahmat[1,2], Siti Rashidah Mohd Zain[3]

[1]Department of Audiology and Speech Language-Pathology, Kulliyyah of Allied Health Sciences, International Islamic University Malaysia, 25200, Pahang, Malaysia
[2]Children Health and Wellbeing research Group, Kulliyyah of Allied Health Sciences, International Islamic University Malaysia, 25200, Pahang, Malaysia
[3]Department of Otorhinolaryngology Sultan Ahmad Shah Medical Centre, International Islamic University Malaysia, 25200, Pahang, Malaysia

*Corresponding author: Ahmad Aidil Arafat Dzulkarnain, ahmadaidil@iium.edu.my

Keywords:
Narrow Band Level Specific CE-Chirp; Fmp; auditory brainstem response; hearing threshold estimation; infants.

ABSTRACT

Background and Aims: Despite advancements in auditory brainstem response (ABR) stimuli, the clinical application of narrow-band level-specific CE-Chirp (NB LS CE-Chirp) and the objective F-test multiple points (Fmp) algorithm remains underexplored, particularly in infant populations. These methodologies hold promise for improving the efficiency of ABR assessments and universal newborn hearing screening. This study evaluates the use of NB LS CE-Chirp as a test stimulus and the Fmp statistical algorithm as a stopping criterion to address prolonged ABR test durations. **Subjects and Methods:** Fifty infants (27 males, 23 females) under six months of age were enrolled. ABR recordings were obtained using both NB LS CE-Chirp and tone burst (TB) stimuli at 500, 1000, and 4000 Hz, presented at 70 and 40 dBnHL. Test durations were calculated using two stopping criteria: Fmp ≥ 3.1 and visual detection. **Results:** NB LS CE-Chirp stimuli elicited significantly shorter test durations across all frequency and intensity combinations compared to TB stimuli, under both Fmp ≥ 3.1 and visual detection criteria. Notably, the Fmp ≥ 3.1 algorithm did not consistently yield shorter test times than visual detection for either stimulus type. **Conclusion:** The use of NB LS CE-Chirp stimuli, combined with either visual or Fmp-based detection algorithms, presents a promising strategy for infant hearing assessment. This approach significantly reduces ABR test duration and may enhance the efficiency of newborn hearing screening protocols.

INTRODUCTION

Universal Newborn Hearing Screening (UNHS) programs, implemented both in Malaysia and globally, aim to identify infants with congenital hearing loss at the earliest possible stage. These initiatives are aligned with the recommendations of the Joint Committee on Infant Hearing (JCIH), which advocate for Early Hearing Detection and Intervention (EHDI) protocols. According to EHDI guidelines, newborns should undergo hearing screening within the first day of life or, at the latest, by one month of age. A confirmed diagnosis of hearing loss is expected by two months, followed by initiation of aural rehabilitation before three months of age. This structured timeline facilitates timely audiological follow-up and intervention (Malaysia Ministry of Health Screening Committee, 2014).

In Malaysia, audiological services face several challenges in achieving these benchmarks, particularly in rural and remote regions. Barriers include limited access to newborn hearing screening (NHS) programs, delays in follow-up diagnostics such as auditory brainstem response (ABR) testing, and insufficient coordination among healthcare providers. These delays are often attributed to long waiting lists and the inherently time-intensive nature of ABR procedures (Cain et al., 2020).

Conventional ABR stimuli, such as clicks and tone bursts, typically require extended testing durations and may necessitate multiple sessions. This contributes to reduced appointment availability and prolonged waiting periods in clinical settings. Moreover, successful ABR recordings depend on the infant being in a quiet or sleep state to complete a full sweep cycle, typically around 2000 sweeps, which is critical for effective signal averaging and enhancement of the signal-to-noise ratio (SNR).

* *Corresponding author.*
E-mail address: ahmadaidil@iium.edu.my

Journal homepage: https://journals.iium.edu.my/ijahs/index.php/IJAHS
EISSN NO 2600-8491

Consequently, some patients may require two to three separate visits to complete the assessment (Cain et al., 2020).

NB LS CE-Chirp is a recent advancement in frequency-specific auditory brainstem response (FS ABR) stimulus. This stimulus presentation duration varies with stimulus intensity and is precisely calibrated to account for cochlear traveling wave delays at central frequencies of 500, 1000, 2000, and 4000 Hz, thereby enhancing ABR amplitude elicited via tone burst stimulus; however, the study was conducted in adult population (Megha et al., 2019; Cebulla & Elberling, 2010). In addition, it was observed that amplitude elicited from ABR to tone burst is usually 70% smaller than the amplitude of ABR to click as the tone burst is a FS ABR stimulus encompassing a specific frequency range which elicited less robust overall response (Ferm et al., 2013). Due to its ability to elicit robust neural responses, NB LS CE-Chirp may achieve an adequate SNR more rapidly, potentially reducing overall test duration. In contrast, tone burst stimulus at 500 to 4000 Hz with low to moderate stimulus intensity levels produce less robust and earlier latency of waves (I, II, III and IV), and these early peaks are misinterpreted as wave V. From previous literature, poor quality ABR was produced by tone burst, specifically at 500 Hz, in which the waves are complex with unstable responses for visual detection (Pinto & Matas, 2007).

To our knowledge, no published studies have directly compared ABR acquisition times between NB LS CE-Chirp and conventional tone burst stimuli in infants. Dzulkarnain et al. (2018) studied the effects of different electrode configurations on the NB LS CE-Chirp and tone-burst auditory brainstem response at multiple intensity levels and frequencies in normal hearing adult. The current study aims to compare ABR acquisition times using NB LS CE-Chirp and tone burst stimuli at frequency-specific levels of 500, 1000, and 4000 Hz, employing two stopping criteria using visual detection and Fmp ≥ 3.1 at 70 and 40 dBnHL in infants with normal hearing.

MATERIALS AND METHODS

Participants recruitment

This study received ethical approval from the Kulliyyah Postgraduate and Research Committee (KPGRC), IIUM Research Ethics Committee [IREC 2023-065], Medical Research and Ethics (MREC) National Medical Research Registration [(NMRR) ID-23-01821-J12 (IIR)], and Sultan Ahmad Shah Medical Centre (SASMEC) approval from the Department of Ear, Nose, and Throat (ENT) and Department of Obstetrics and Gynaecology (O & G). Fifty infants (27 males and 23 females) aged below 6 months old with a mean age of 2.55 months (SD = 0.83) met the inclusion criteria of 1) normal ear canal and middle ear conditions, 2) passed the neonatal hearing screening program using distortion product otoacoustic emissions (DPOAE), 3) Type A high-frequency tympanogram suggesting normal middle ear function based on Jerger classification, 4) no history of otological diseases, 5) no upper respiratory tract infection (URTI) symptoms at least two weeks before appointment day, and 6) infants without high-risk factors of hearing loss, according to JCIH (2019). Participants were identified and selected from the Department of Obstetrics and Gynaecology (O&G) and Otorhinolaryngology (ORL) at SASMEC. The initial contact was made by the researchers via telephone or during an appointment, where the study was introduced and an appointment was scheduled. Informed consent was subsequently obtained in person during the scheduled appointment, which was also conducted by the researcher.

Methods

The study was conducted in a sound-treated room at IIUM Hearing and Speech Clinic, Jalan Hospital Campus, Kuantan, Pahang. In this study, ABR measurements were conducted using the Interacoustics Eclipse EP25 system. ABR assessment was performed in a sound-treated room, and the stimulus was given via ER-3A (Etymotic Research) insert earphones. The ABR using NB LS CE-Chirp and tone burst stimuli were tested at three specific frequencies of 500, 1000, and 4000 Hz at 70 and 40 dBnHL using a 33.33 Hz stimulus rate with filter settings 33Hz for high-pass and 3000 Hz for low-pass, and ≤ 40 microvolt artifact rejection.

Subjects need to be in a relaxed state and, if possible, sleep on the bed or on the caretaker's lap during the recording session to reduce muscle artifact at low frequencies. Subjects were under natural sleep without sedation. ABR was recorded using a two-channel function through four electrode locations. Before placing the electrode, the subject was prepared by scrubbing the respective places for electrode placement using NuPrep Skin Preparation electrode gel. Ipsilateral and contralateral electrode montage was used by placing Ambu Neuroline 720 disposable electrodes on high forehead marks as a non-inverting (Cz) electrode, lower forehead marks as a ground electrode (Fpz), inverting electrodes on both mastoids at 70 and 40 dBnHL, see Table 1 (Dzulkarnain et al., 2018). The electrode impedance was kept below 5 kΩ during all measurements, measured using the ABR Interacoustics Eclipse EP25 impedance check function, and the inter-electrode impedance was balanced. These two-channel configurations were used to obtain information from two distinct locations on the inverting electrode, which are optimal for capturing all ABR peaks (Dzulkarnain et al., 2021).

In this study, the ABR acquisition time was determined using combinations of two stimulus types (NB LS CE-Chirp and tone burst) and two methods of ABR stopping criteria (Fmp and visual detection). The maximum sweep of the test was set to 2500. To quantify the ABR acquisition time, the researcher uses the following steps: i) In this experiment, the researcher "pauses" the signal averaging immediately as the Fmp hits 3.1 (Fmp ≥ 3.1). The Fmp is the statistical F-value for multiple points and provides a better confidence level and detection rate of ABR in less time. Two audiologists confirmed the presence or absence of ABR wave V, recorded and stopped by Fmp ≥ 3.1, using waveform morphology. ii) In terms of visual detection technique, the researcher "paused" the averaging as soon as the ABR waveform occurred and was visually identified. Wave V was plotted, and the number of sweeps at that point was recorded. iii) The ABR acquisition time with various combinations of stimulus types, frequencies, and stopping criteria was documented and analyzed.

Table 1. ABR electrode montages

Electrode Type	Standard Placement Location	Ipsilateral Recording (Example: Left Ear Stimulated)	Contralateral Recording (Example: Left Ear Stimulated)
Non-Inverting (+) / Active	Vertex (Cz) or high forehead (Fpz)	Vertex (Cz) or high forehead (Fpz)	Vertex (Cz) or high forehead (Fpz)
Inverting (-) / Reference	Mastoid or earlobe	Left Mastoid (M1) or Left Earlobe (A1) (same side as stimulus)	Right Mastoid (M2) or Right Earlobe (A2) (opposite side of stimulus)
Ground (⏚)	Low forehead, cheek, or nape of neck	Low forehead, cheek, or nape of neck	Low forehead, cheek, or nape of neck

Statistical analysis

Statistical analysis was measured using IBM SPSS Statistics for Windows, Version 27.0. (IBM Corp., Armonk, NY, USA). The mean differences of ABR test time among the combinations of two stimuli NB LS CE-Chirps and tone burst), two detection types (Fmp and visual detection) at two intensity levels (70 and 40 dBnHL) and three frequencies (500, 1000, and 4000 Hz) were compared using the Wilcoxon signed-rank test at 95% confidence levels.

RESULTS

Fifty ABRs of normal hearing infants using NB LS CE-Chirp and tone burst were collected in this study. Table 1 shows the median and inter-quartile range of the ABR test time for all combinations using two stimuli (NB LS CE-Chirps and tone burst), two detection types (Fmp and visual detection), two intensity levels (70 and 40 dBnHL), and three frequencies (500, 1000, and 4000 Hz).

Table 3 summarizes the number of ABRs identified by the Fmp detection method at two stimulus intensities (70 and 40 dBnHL) across three test frequencies (500, 1000, and 4000 Hz). Consistent detection between the Fmp technique and audiologist confirmation was observed only at 70 dBnHL for both NB LS CE-Chirp and tone burst stimuli at 1000 Hz. For the remaining frequency and intensity combinations, discrepancies were noted, with Fmp detection showing inconsistencies ranging from 2% to 10%.

Tables 4 and 5 show the p-values and effect sizes obtained from the Wilcoxon signed-rank test, which compares ABR test times across all test combinations.

Comparison of ABR test time between ABR from NB LS CE-Chirp and tone burst

The results from Tables 2, 4 and 5 indicate that ABRs elicited by the NB LS CE-Chirp stimulus had significantly shorter acquisition times compared to those elicited by tone burst stimuli, across both detection techniques, stimulus intensities, and all test frequencies ($p < 0.05$). The only exception was at 4000 Hz for both intensities using the Fmp detection method, where acquisition times for both stimuli were statistically similar ($p \geq 0.05$). Overall, ABRs acquired using the NB Chirp stimulus were faster by approximately 4.51 to 18.02 seconds with Fmp detection, and 9.02 to 15.02 seconds with visual detection, compared to those acquired using tone burst stimuli.

Comparison of ABR test time between Fmp and visual detection

The results from Tables 2, 4, and 5 indicate that ABRs identified using the Fmp detection method were significantly faster than those identified visually by an audiologist in only 5 out of 12 combinations of stimulus intensity, frequency, and type ($p < 0.05$). At 40 dBnHL, visual detection identified ABRs faster than Fmp when elicited by NB Chirp stimuli at 500 Hz and 4000 Hz ($p<0.05$). For the remaining combinations, both detection techniques yielded ABRs with comparable acquisition times.

DISCUSSION

NB LS CE-Chirp versus tone burst

The comparison of ABR acquisition times using NB LS CE-Chirp and tone burst stimuli at 500, 1000, and 4000 Hz, presented at 70 and 40 dBnHL were observed from this study.

Overall, NB LS CE-Chirp elicited shorter ABR acquisition times than tone burst stimulus. This improvement is likely attributable to the enhanced neural synchrony achieved by NB LS CE-Chirp, a subset of broadband LS CE-Chirp. The stimulus design involves precise timing of frequency components, with lower frequencies presented earlier to compensate for cochlear travel delays. This synchronization allows simultaneous activation of cochlear regions, resulting in larger ABR amplitudes and improved SNR (Ferm et al., 2013; Ferm et al., 2015; Wegner & Dau, 2002; Elberling et al., 2010). In this design, lower-frequency components—which require longer travel distances along the cochlea—are presented earlier than higher-frequency components. This timing strategy allows all frequency components to reach their respective cochlear regions simultaneously, resulting in improved ABR wave amplitudes and enhanced SNR, thereby reducing overall testing time (Ferm et al., 2013; Ferm et al., 2015; Wegner & Dau, 2002; Elberling et al., 2010). Consequently, the faster a stimulus achieves an adequate

Table 2. The median and inter-quartile range (IQR) for ABR acquisition time produced via NB LS CE-Chirp and tone burst stimuli at multiple frequencies and intensities using both stopping criteria in normal hearing infants.

Acquisition time (s)	Intensity (dBnHL)		Fmp			Visual	
		Frequency (Hz)					
Stimuli		500	1000	4000	500	1000	4000
NB LS CE-Chirp	**70**	6.01 (9.01)	4.50 (9.01)	9.01 (12.76)	12.01 (9.01)	12.01 (9.01)	9.01 (9.01)
Tone burst		16.52 (25.33)	9.01 (12.76)	6.06 (9.76)	21.02 (18.77)	21.02 (12.01)	21.02 (6.76)
NB LS CE-Chirp	**40**	16.52 (27.03)	12.01 (24.77)	12.01 (21.77)	15.01 (6.76)	15.01 (6.77)	10.51 (9.01)
Tone burst		33.03 (40.54)	30.03 (45.80)	15.01 (27.03)	27.03 (15.77)	30.03 (21.02)	24.02 (12.01)

Table 3. Number of ABR wave V identification using Fmp 3.1 versus number of wave V confirmed by an audiologist at frequency specifics and intensities in normal hearing infants.

Stimulus types	Stimulus frequency (Hz)	Intensity (dBnHL)	No. of wave V identified by Fmp≥ 3.1	No. of wave V confirmed by Audiologist	Percentages of discrepancies (%)
NB LS CE-Chirp	500	70	49	48	2.04
Tone burst			49	47	4.08
NB LS CE-Chirp		40	48	46	4.17
Tone burst			47	46	2.13
NB LS CE-Chirp	1000	70	50	50	0
Tone burst			50	50	0
NB LS CE-Chirp		40	50	47	4.00
Tone burst			50	45	10.00
NB LS CE-Chirp	4000	70	50	47	6.00
Tone burst			50	47	6.00
NB LS CE-Chirp		40	50	45	10.00
Tone burst			50	46	4.00

Intensity (dBnHL)	Stopping criteria	Stimulus	Frequency (Hz)	*p*-value											
				Fmp						Visual					
				NB LS CE- Chirp			Tone burst			NB LS CE- Chirp			Tone burst		
				500	1000	4000	500	1000	4000	500	1000	4000	500	1000	4000
70	Fmp	NB LS CE-Chirp	500				*<0.001			0.05					
			1000					*<0.001			*<0.001				
			4000						0.05			*0.001			
		Tone burst	500										0.138		
			1000											*0.005	
			4000												*<0.001
	Visual	NB LS CE-Chirp	500				*<0.001						*<0.001		
								0.09						*<0.001	
			4000						0.14						*<0.001
		Tone burst	500	*<0.001											
			1000		*<0.001										
			4000			*<0.001									

Table 4. The *p*-values of the post hoc analysis Wilcoxon signed-rank test for acquisition time at multiple stimulus frequencies at 70 dBnHL in normal hearing infants

Intensity (dBnHL)	Stopping criteria	Stimulus	Frequency (Hz)	*p*-value											
				Fmp						Visual					
				NB LS CE- Chirp			Tone burst			NB LS CE- Chirp			Tone burst		
				500	1000	4000	500	1000	4000	500	1000	4000	500	1000	4000
40	Fmp	NB LS CE-Chirp	500				*0.001			*<0.001					
			1000					*0.001			0.02				
			4000						0.06			*<0.001			
		Tone burst	500										0.03		
			1000											0.09	
			4000												*<0.001
	Visual	NB LS CE-Chirp	500				*<0.001						*<0.001		
			1000					*<0.001						*<0.001	
			4000						*<0.001						*<0.001
		Tone burst	500	0.030											
			1000		*<0.001										
			4000			*0.006									

Table 5. The *p*-values of the post hoc analysis Wilcoxon signed-rank test for acquisition time at multiple stimulus frequencies at 40 dBnHL in normal hearing infants

SNR, the shorter the acquisition time—regardless of the detection technique employed. Similar findings have also been reported in studies involving adult subjects (Dzulkarnain et al., 2023). The improvement of test time is important because infants are particularly vulnerable to sensory overload and extended time can cause fatigue or discomfort (Graven & Browne, 2008). The enhanced efficiency of the NB LS CE- Chirp in reducing acquisition times holds clinical significance (Cebulla & Elberling, 2010) particularly for infants, as it minimizes testing duration and discomfort. ABR amplitude is higher elicited via NB LS CE-Chirp stimulus. Therefore, the likelihood of faster ABR detection due to the reduction in the number of averaging sweeps required for effective noise attenuation. NB LS CE chirp produced higher amplitude than tone burst because the neural synchronization is more optimum and wider in NB chirp than in tone burst.

Fmp and visual detection method

The curreny study also sought comparison between two stopping criteria of ABR detection times which were visual detection and Fmp ≥ 3.1, in infants with normal hearing. The present study did not yield compelling evidence supporting the superiority of the Fmp ≥ 3.1 stopping criterion over visual detection in terms of ABR acquisition time, refer Table 3.

Furthermore, notable no discrepancies were observed between ABRs identified by the Fmp technique and those validated by an audiologist. The discrepancy is higher at lower intensity than high intensity because of poor SNR typically at low intensity levels.

To our knowledge, no published study to date has directly compared ABR detection using the Fmp method against visual detection for the infant population. These findings highlight three important considerations regarding the clinical application of the Fmp detection method in audiology practice. Objective detection techniques, such as Fmp, should be considered complementary to clinical visual interpretation in ABR assessment (NHSP, 2013; BSA, 2018). At 4000 Hz, there is no significant different between NB LS CE-Chirp and tone burst stimuli, this may be due to need more sample to identify the small differences. The expert judgment of audiologists remains the gold standard for ABR identification with Fmp values serving as useful indicators for verifying the SNR when confirming responses. Fmp enhances the efficiency of ABR detection by allowing real-time SNR verification, thereby reducing reliance on fixed sweep counts. When Fmp used combined with visual detection, Fmp can shorten ABR testing time by concluding tests once sufficient data is collected, thus minimizing unnecessary auditory stimulation. While the Fmp cutoff value of 3.1 is appropriate at suprathreshold levels, it may not be suitable as stimulus intensity approaches threshold levels. The use of Fmp as a stopping criterion relies on SNR calculations that contribute to the robustness of the ABR waveform and facilitate faster algorithmic achievement of the Fmp threshold in NB LS CE-Chirp designs compared to tone bursts (Mckearney et al., 2010). This modified structure improves ABR waveform characteristics, leading to better testing efficiency overall. This limitation becomes more pronounced in low intensity recordings where neural synchrony and signal strength are reduced. Therefore, future studies should consider utilizing lower Fmp cutoff values corresponding to 95% or 90% confidence levels, equivalent to 2.25 and 1.80, respectively. Infants are particularly vulnerable to sensory overload and extended exposure to auditory stimuli can cause fatigue or discomfort (Graven & Browne, 2008). This approach ensures that ABR waveforms are captured during periods of optimal responsiveness of the auditory system in infants enhancing the reliability and accuracy of test results. Accurate ABR testing is crucial for early identification of hearing impairments, enabling timely intervention, and improved long term outcomes (JCIH, 2009).

CONCLUSION

This study concluded that ABR recorded from NB LS CE-chirp was faster than ABR to tone bursts at multiple frequencies and intensities, using both stopping criteria, in normal-hearing infants. The findings from the current study only focus on normal hearing infants below 6 months of age and are limited to the specific stimulus, recording parameters, and equipment used.

Future research should aim to validate these findings across broader populations, encompassing various types and severities of hearing loss. Additionally, the future study should investigate the correlation between objective ABR thresholds and behavioral hearing thresholds in older pediatric populations to assess consistency and clinical applicability.

ACKNOWLEDGEMENT

The authors wish to acknowledge the Ministry of Health Malaysia for their financial support in conducting this study. This project was partly funded by the International Islamic University Malaysia Research Matching Grant Scheme (RMGS24-004-0035). Special thanks are extended to the Department of Obstetrics and Gynaecology, SASMEC, and the Department of Otorhinolaryngology, SASMEC, for granting approval and facilitating data collection for this study.

REFERENCES

Cain, S. E., Gomes, T., Leisner, D., Lenzen., N., Rall, E., Schicke, E., and Uhler, K. M. (2020) Clinical Guidance Document Assessment of Hearing in Infants and Young Children. American Academy of Audiology Assessment of Hearing in Infant and Young Children

Cebulla, M. and Elberling, C. (2010). Auditory brain stem responses evoked by different chirps based on different delay models. Journal of American Academy Audiology. 21, 452-460.

Dzulkarnain, A. A. A., Abdullah, S. A., Ruzai, M. A. M., Ibrahim, S. H. M. N., Anuar, N. F. A., and Rahim, A. E. A. (2018). Effects of different electrode configurations on the narrow band level-specific CE-chirp and tone-burst auditory brainstem response at multiple intensity levels and frequencies in subjects with normal hearing. American Journal of Audiology, 27(3), 294–305. https://doi.org/10.1044/2018_aja-17-0087

Dzulkarnain, A. A. A., Marzuki, M. N., Shahrudin, F. A., Jamal, F. N., Chahed, N., and Zakaria, M. N. (2023). Optimization of Auditory Brainstem Response (ABR) Test Time using Level Specific (LS) CE-Chirp. International Journal of Allied Health Sciences, 7(1), 2820–2826. https://doi.org/10.31436/ijahs.v7i1.731

Dzulkarnain, A. A. A., Salamat, S., Shahrudin, F. A., Jamal, F. N., and Zakaria, M. N. (2021). Influence of Stimulus Polarity on the Auditory Brainstem Response from Level-Specific Chirp. Journal Audiology Otology, 25(2), 199-208. https://doi.org/10.7874/jao.2021.00248

Elberling, C., Callo, J., & Don, M. (2010). Evaluating auditory brainstem responses to different chirp stimuli at three levels of stimulation. Journal of the Acoustical Society of America, 128(1), 215–223. https://doi.org/10.1121/1.3397640

Ferm, I., and Lightfoot, G. (2015). Further comparisons of ABR response amplitudes, test time, and estimation of hearing threshold using frequency-specific chirp and tone pip stimuli in newborns: Findings at 0.5 and 2 kHz. International Journal of Audiology, 54(10), 745–750. https://doi.org/10.3109/14992027.2015.1058978

Ferm, I., Lightfoot, G., and Stevens, J. (2013). Comparison of ABR response amplitude, test time, and estimation of hearing threshold using frequency specific chirp and tone pip stimuli in newborns. International Journal of Audiology, 52(6), 419–423. https://doi.org/10.3109/14992027.2013.769280

Graven, S.N. and Joy V. Browne, J. V. (2008). Auditory Development in the Fetus and Infant, Newborn and Infant Nursing Reviews, 8(4), 187-193, https://doi.org/10.1053/j.nainr.2008.10.010

McKearney, R. M. and MacKinnon, R. C. (2019). Objective auditory brainstem response classification using machine learning. International Journal of Audiology, 58(4), 224–230. https://doi.org/10.1080/14992027.2018.1551633

Megha, K. N., Divyashree, K. N., Lakshmi, A., Adithya, S., Keerthana, K. P., Pushpalatha, Z. V., Konadath, S. (2019). Narrow-band chirp and tone burst auditory brainstem response as an early indicator of synaptopathy in industrial workers exposed to occupational noise. Hearing Balance Communication, 16(1): 1–12. https://doi:10.1080/21695717.2017.1418 803

NHSP (2013). Sutton, G., Lightfoot, G., Contributors: Stevens, J., Booth, R., Brennan, S., Feirn, R., and Meredith, R. Guidance for Auditory Brainstem Response testing in babies.

Pinto, F.R. and Matas, C.G. (2007). A comparison between hearing and tone burst electrophysiological thresholds. Brazillian Journal Otorhinolaryngology. 73(4):513-22. https://doi: 10.1016/s1808-8694(15)30103-8

Wegner, O., and T. Dau, T. (2002). Frequency specificity of chirp-evoked auditory brain stem responses, Journal of the Acoustical Society of American. 111, 1318–1329.

Joint Committee on Infant Hearing. (2019). Year 2019 Position Statement: Principles and Guidelines for Early Hearing Detection and Intervention Programs. Journal of Early Hearing Detection and Intervention, 4(2).