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Effect of the arousal state on automatic detection of cortical auditory evoked responses in neonates

Efeito do estado atencional na detecção automática das respostas auditivas corticais em neonatos

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ABSTRACT

Purpose: The aim of the present study was to compare latency and amplitude of the cortical auditory evoked response P1i among newborns in an alert state and during light sleep. **Methods:** Twenty-five neonates with normal transient evoked otoacoustic emissions were tested with cortical auditory evoked potentials (CAEP): 10 were in an alert state and 15 in light sleep during testing. For the investigation of cortical potentials, a single-channel Hearlab System equipment, Cortical Tone Evaluation module (CTE), was used. The P1i potential was investigated monoaurally at an 80dBnHL intensity at 500, 1000, 2000 and 4000 Hz. P1i was automatically detected by the equipment. Latency and amplitude were marked by three judges. The responses of the newborn in an alert state were compared with those in light sleep. **Results:** There was no statistically significant difference between the two groups of neonates for the amplitude and latency values at the four tested frequencies. **Conclusion:** There was no influence of the neonates' behavioral state on the evaluation of the P1i auditory cortical potential.

Keywords: Evoked potentials, Auditory; Sleep; Hearing; Infant, Newborn; Electrophysiology

RESUMO

Objetivo: O objetivo desse estudo foi comparar a latência e amplitude do potencial evocado auditivo cortical P1i entre neonatos em estado de alerta e durante o sono leve. **Métodos:** Vinte e cinco neonatos com emissões otoacústicas evocadas transientes presentes foram testados, por meio do potencial evocado auditivo cortical (PEAC), sendo dez em estado de alerta e 15 durante o sono leve. Para pesquisa dos potenciais corticais, utilizou-se o equipamento *Hearlab System*, de um canal, no módulo *Cortical Tone Evaluation (CTE)*. O potencial P1i foi pesquisado de forma monoaural, na intensidade de 80 dBnNA, para as frequências de 500, 1000, 2000 e 4000Hz. A detecção do P1i foi feita de maneira automática pelo equipamento. A marcação da latência e amplitude foi realizada por três juízes. **Resultados:** Não houve diferença estatisticamente significativa entre os dois grupos de neonatos para os valores de amplitude e latência, nas quatro frequências testadas. **Conclusão:** Não houve influência do estado comportamental dos neonatos na avaliação do potencial cortical P1i.

Palavras-chave: Potenciais evocados auditivos; Sono; Audição; Neonatos; Eletrofisiologia

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INTRODUCTION

The Cortical Auditory Evoked Potentials (CAEP) were discovered in the 1930s and thoroughly researched in the 1960s and 1970s[1,2]. However, with the discovery of short-latency potentials, and due to difficulties in achieving the CAEP, such evaluation has not been frequently used in the clinical practice, especially in children under 12 months[1,2]. The difficulties of this assessment in very young children are mainly due to the maturational issues, which influence the interpretation of the results[1]. In addition, although it is found that newborns learn during sleep[3] the assessment auditory cortical evoked potentials during different behavioral stages on neonatal period is controversial in the literature[4].

With the advancement of technology, some devices allow an automatic CAEP analysis, thus making it easier to use and an important tool in assessing the arrival of the acoustic stimulus in the auditory cortex[5,6]. The Hearlab System equipment, developed by the National Acoustic Laboratories (NAL) in Australia, has brought greater reliability of cortical responses, allowing the audiologist to rethink the use of CAEP both in research and in the clinical practice. In early latency responses, the evoked potentials are relatively stable, but in late latency evoked potentials, detection can be impaired by the instability of the true evoked potential, as well as residual noise. So, methods that reduce residual noise are needed[7].

Among the main clinical applications, the verification of hearing aids[8], cochlear implants[9], monitoring the maturational process in different populations[9-12] and the investigation of the cortical threshold[5,13] are the main objectives of this assessment.

In adults, the CAEP is defined as the complex P1-N1-P2, being that the latency and amplitude are influenced by the characteristics of the stimuli[1,14]. The amplitude refers to the magnitude of the response, being measured in in microvolts (μV), whereas latency is referred as the response time after the acoustic stimulus, and is measured in milliseconds (msec)[14]. These responses refer to the amount of neurons responsive to a sound stimuli, the number of neurons recruited, the extend of neural activation and neural synchrony. Thus, the P1-N1-P2 complex reflects the detection of the acoustic stimulus at central level, reflecting the excitatory postsynaptic potentials at the level of the thalamus and higher auditory cortex, being the primary auditory cortex and association areas[14].

In children, the response is classified by a peak of greater prominence[15], followed by a broad negative trough[1]. The obligatory cortical auditory evoked potential is mainly comprised of the positive peak, that occurring between approximately 90-300ms in infancy and early childhood[15]. Other studies, involving different populations, like children with hearing loss, and with different types of stimuli, like speech stimuli, describes that this positive peak, which is the most visible component, occurs at about 200-300ms[16-18]. This component can be evidenced as early as in the first years of life in children due to the fact that it is related mainly to the detection of the stimulus in the auditory cortex[10,19,20]. Due to the fact that these potentials are exogenous, the type of stimulus influences the morphology and results obtained[1]. The positive peak has most commonly been labeled as P2 and the later negative deflection as N2. However, results between studies should be carefully interpreted, since the nomenclatures vary between laboratories and the children's cortical potentials are different from those seen in adults[4].

The CAEP can be elicited with a variety of stimuli, but the use of tone burst of different frequencies may reflect the organization of cortical generators and their development[1], being important in the maturational auditory investigation.

The behavioral state of children during the electrophysiological assessments is an important factor for detection of auditory responses. For short-latency auditory evoked potentials it is necessary for the individual to be in a state of sleep[21], while there is influence of the behavioral state for cortical and middle auditory evoked potentials, since assessments depend on skills such as attention and auditory discrimination[2,20].

Because it is an exogenous potential, the cortical auditory response is related to the detection of the acoustic stimulus in the primary auditory cortex[22]. The behavioral status of very young children during evaluation of cortical auditory evoked potentials has been debated in the literature[4] but there is a shortage of studies involving this topic in neonates.

Newborns spend amount of time sleeping and the auditory information may enter the brain even in this state[3]. The period of active and quiet sleep is present after 35 weeks post-conception, and can be detected by behavioral observation[23]. The brain activation is markedly different in the two sleep states: during active sleep the neonatal brain is similar to wakefulness[24]. By contrast, during quiet sleep, a decreased cortical activation is observed[24]. The active, only called light or REM (Rapid Eye Movement) sleep is the prevailing sleep stage in the newborn[25].

The electroencephalographic patterns in neonates in active sleep cannot be differentiated from those of awake state[26]. Other study also describes that light/active sleep would not affect the response related to the detection of the stimulus in the auditory cortex[27]. In contrast, researchers[20] report that the behavioral state can have an influence on amplitude. Besides that, they[20] add that the speech stimuli evoke larger responses amplitudes in neonates due to the significance of the stimulus.

The knowledge about the influence of the behavioral state of the neonate on the cortical auditory potential is extremely useful, as it allows one to obtain information about the brain function since the neonatal period.

The hypothesis guiding this study is that the behavioral state exerts no influence on the cortical responses in neonates, since the cortical auditory evoked potential is elicited upon detection of the acoustic stimulus in the primary auditory cortex. The possibility of obtaining cortical responses during light sleep in neonates, which could facilitate the applicability of CAEP in this age group, justifies this study, since responses are very difficult to be obtained due to the large number of artifacts that arise from employing usual equipment when assessing neonates who remain in the waking state.

Considering the above, this study aimed to compare the P1i auditory cortical potential responses among newborns in an alert state and during light sleep in order to assess the influence these two behavioral stages exert over responses.

METHODS

This is an observational, cross-sectional, analytical and contemporary study on neonates treated at the Audiology and Speech Therapy Clinic at the Faculdade de Ciências Médicas da Santa Casa de São Paulo teaching hospital.

This study was conducted through a partnership between Universidade Federal do Rio Grande do Sul and Faculdade de Ciências Médicas da Santa Casa de São Paulo, and approved by the Research Ethics Committees at both institutions under register number 44965015.8.1001.5334 and 40667415.0.0000.5479.

The sample was consisted in a non-probabilistic fashion, as per convenience. Only neonates whose parents or guardians, after receiving information on the objectives and methodology of the study, agreed to the procedures to be performed and who signed the Voluntary and Informed Consent Form (VICF), complying with the resolution 466/12 on research involving human subjects, participated in the study.

The study enrolled 25 full-term neonates with up to 28 days of life, of both sexes, with bilaterally present transient evoked otoacoustic emissions and without risk indicators for hearing loss, in accordance with the Joint Committee on Infant Hearing (JCIH, 2007)[28]. Neonates with hearing loss, neurological disorders and/or syndromes were excluded from the study. Newborns with a gestational age equal to or greater than 37 weeks were considered to be full-term neonates[29].

The evaluations were undertaken at an electrically and acoustically treated room, and the neonates were held on the lap of their parents/guardians, who were seated in a comfortable armchair. Prior to the conduction of the tests, the neonates underwent visual inspection of the external acoustic meatus bilaterally, and the ear canals were not obstructed.

Transient otoacoustic emissions (TOAE) were measured in both ears with a nonlinear click stimulus, 20-ms window, at 1000, 1500, 2000, 3000 and 4000 Hz, with an intensity of approximately 80 dBSPL. TOAE were considered present when the signal/noise ratio was greater than or equal to 3 dB for the frequency of 1000Hz and 6 dB for all other frequencies, in at least three of the five frequencies measured. The recording of TOAE was made in quiet place with an Otometrics AccuScreen device.

For the investigation of CAEP, 25 newborns were divided into two groups: 10 newborns remained in an alert state (Group 1 – G1), five males and five females, and 15 newborns remained in light sleep (Group 2 – G2), six males and nine females.

The behavioral state of neonates was controlled by two judges, who monitored the newborns throughout the evaluation. The identification of the behavioral state of neonates was based on the criteria described in the Neonatal Behavioral Assessment Scale (Brazelton Scale)[30]. This scale has six behavioral states: State 1: deep sleep; State 2: light sleep, closed eyes, some body movement; State 3: sleepy, eyes opening and closing; State 4: awake, open eyes, minimum body movements; State 5: fully awake, vigorous body movements; State 6: crying. The G1 neonates remained between states 4, whereas the G2 neonates remained between states 2 and 3.

For the investigation of cortical potentials, a single-channel Hearlab equipment, Cortical Tone Evaluation module (CTE), was used. This equipment has specific filters for controlling artifacts as the child moves her or his body, thereby ensuring the reliability of cortical responses. The residual noise was controlled during all assessment and the Hearlab incorporates a display which indicates the quality of the cortical response recorded in relation to the noise level of the signal. A residual noise level value less or equal to 3.2 μV indicates a good quality recording; a value between 3.2 and 3.6 μV indicates a slightly compromised recording and a value higher than 3.6 μV indicates a poor quality recording. In this study, the maximum value allowed for noise was 3.6 μV and for this reason participants with extreme agitation and excess movement were excluded. In this study two participants were excluded for this reason. The ambient noise level did not exceed 35 dB A. In addition, all neonates have cortical auditory evoked responses in at least 35 dBnHL. This response was investigated in order to exclude possible participants with suspected hearing loss.

The stimuli was a 40-msec tone burst presented through insert earphones, and the responses were then measured at the frequencies of 500, 1000, 2000 and 4000 Hz in the intensity of 80 dBnHL in order to assess response latency and amplitude. The side to be assessed was randomly chosen. Each participant was evaluated on only one side due to the fact that the equipment was of one channel, and did not allow the simultaneous evaluation of both ears. Besides that, due to brain immaturity in the neonatal period, the hemispheric dominance was not taken into account in the present study. The intensity was chosen in order to obtain a better morphology of the responses, since the amplitude is greater at higher intensity[19,31].

The reference electrode was placed on the right (M2) or left (M1) mastoid whereas the active electrode was placed on the vertex (Cz) and the ground electrode, on the forehead (Fpz). Prior to attaching the electrodes to the skin of neonates, it was prepared with the aid of gauze and an abrasive paste (Nuprep®). The impedance was maintained at or below 5 kohms throughout the assessment.

The parameters for assessing cortical auditory evoked potentials were: stimuli tone burst, with an alternating polarity, interstimulus interval of 1.125 msec, duration of 40 msec, 0.5 stimulation/sec, rise-fall of 10 msec, plateau of 30 msec, filter high-pass: 0.16 Hz; Low-pass: 0.30 Hz and cosine envelope.

The presence or absence of cortical responses (P1i) was automatically analyzed by the equipment, which applies Hotelling's T2 statistical analyses to analyze the signal/noise ratio of the responses obtained at each one of the frequencies measured. In this case, each sample was divided into nine portions within the analysis period of 50ms each in a window of up to 500ms. The mean of each point was tested using the multivariate analysis of variance. The applied statistical test tested the waveform hypothesis to be different from random noise. Responses were considered present when the obtained p-value was less than or equal to 0.05, that is, when the response was greater than the noise. We used at least 50 accepted stimuli to evoke cortical responses. The cortical auditory evoked potentials require less stimuli when compared to a short latency evoked potential, since the habituation of responses in central auditory system[7]. When the response was obtained and considered statistically significant by the equipment, with at least 50 stimuli, the evaluator paused the test.

One recording was performed for each frequency due to the fact that it is an automatic analysis equipment and does not allow the visualization of two tracings simultaneously. This protocol is in agreement with the recommendations of procedures for research of the CAEP[2], which cites this type of assessment in equipment with automatic analysis.

The identification and marking of potential latency and amplitude was performed manually because the equipment does not have the latency and amplitude marking. In order to ensure the reliability of the results, three judges with experience in hearing electrophysiology marked the results. The examiners were oriented to mark the P1i (p= positive; 1= first peak, i= infant) as the first highest positive and visible peak that could be observed in 500ms window. The amplitude was measured from the baseline (zero point) to the point of greatest amplitude of the peak. The effectiveness of an automated statistic detection versus experienced examiners in detecting the presence of infant CAEP has already been studied in another research, evidencing the reliability of the automatic responses[7]. The figure 1 show an example of cortical auditory evoked potentials in a neonate of this study.

The data were tabulated in Excel and analyzed with the aid of the Statistical Package for Social Sciences version 20.0 software for Windows. A two-way ANOVA with the between factor Group and with a repeated measure for factor Frequency was performed for the two dependent variables latency (msec) and amplitude (microVolt).

RESULTS

The descriptive variables of the neonates who participated in the study are shown in Table 1.

For latency, there was no significant effect for group, F(1,23)=0.63, p=0.44; no significant effect for frequency, F(3,69)=0.49, p=0.69; and no significant effect for interaction between group and frequency, F(3,69)=0.46, p=0.71 (Table 2).

For amplitude, there was no significant effect for group, F(1,23)=0.28, p=0.60; no significant effect for frequency, F(3,69)=0.98, p=0.41; and no significant effect for interaction between group and frequency, F(3,69)=0.79, p=0.50 (Table 3).

Table 1. Gestational age and age on the date of the assessment, by group

	Gestational age (weeks) [min-max]	Age on the day of the assessment (days) [min-max]
G1(n=10)	39.5 [38 – 41]	10.9 [7 – 16]
G2(n=15)	39.8 [38 – 41]	9.8 [6 – 22]

Legend: min=minimum; max=maximum; G1=group1; G2=group 2.

Table 2. P1i mean latency values at the intensity of 80 dB nHL by frequency and group.

Frequency	Average lat [min-max] (msec) G1 (n=10)	SD	Average lat [min-maxi] (msec) G2 (n=15)	SD
500Hz	230 [140-359]	61.02	251.53 [164-343]	43.39
1000Hz	220.60 [125-283]	52.56	246.67 [187-399]	57.03
2000Hz	247.2 [180-353]	57.82	249.93 [182-368]	48.68
4000Hz	244.3 [112-379]	82.29	246.20 [168-370]	50.67

Legend: lat=latency; min=minimum; max=maximum; msec= milliseconds; SD= standard deviation

Table 3. P1i mean amplitude values at the intensity of 80 dB nHL by frequency and group

Frequency	Mean amp G1[min-max] (n=10)	SD	Mean amp G2[min-max] (n=15)	SD
500Hz	6.89 [1.11-12.71]	3.75	7.25 [1.39-18.78]	4.52
1000Hz	7.38 [2.45-12.57]	2.67	9.12 [3.84-21.83]	5.36
2000Hz	8.00 [4.07-12.81]	3.11	7.33 [2.6-14.49]	3.42
4000Hz	6.49 [2.5-10.65]	2.78	7.57 [2.77-15.95]	3.04

Legend: amp= amplitude; min=minimum; max=maximum; uV= microvolts; SD= standard deviation

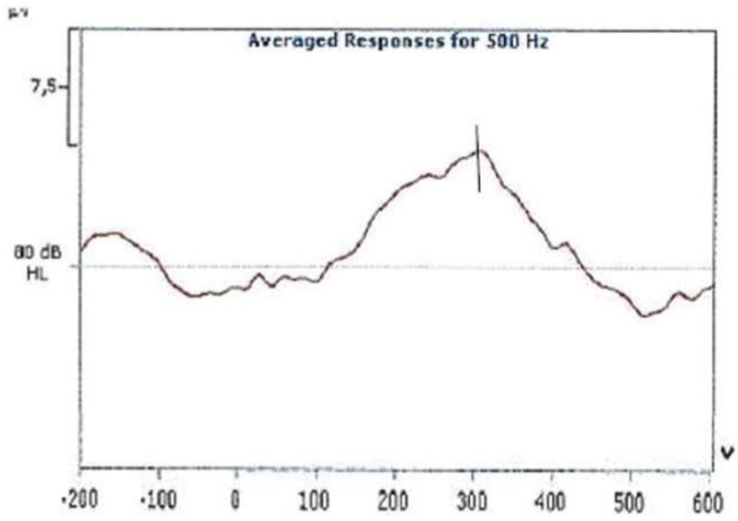

Figure 1. Example of cortical auditory evoked potential in 500Hz in a neonate of the present study. The vertical line in the wave show the marked identified by the judges.

DISCUSSION

In this study, it was possible to detect the P1i wave at an intensity of 80 dBnHL in newborns both in light sleep and wakefulness. These results are consistent with other studies[22,27,32,33], in which the P1 component was detected during different behavioral states. Although the cortical activity is different for each stage of sleep, the detection of the acoustic stimulus in the primary auditory cortex would be similar during both sleep and wakefulness, by which fact the P1 potential could be detected in these behavioral states in the age group studied.

In this study, there was no statistically significant difference between the groups assessed for latency and amplitude. The latency averages of the P1i component of both groups were observed to be in agreement with the values proposed in the literature for the pediatric population[12,17-19]. Some authors[20] go on to indicate that latency can be influenced, even though the morphology of the waveform may be similar across different behavioral states. This was not observed in this study, but we suggest further research be conducted with a larger sample size.

With regard to the amplitude, researchers report that both the behavioral state and the type of acoustic stimulus can have a direct influence on this variable, and speech stimuli evoke larger responses amplitudes in neonates due to the significance of the stimuli[20]. In this study, tone burst stimuli were used due to equipment availability, and there was observed no difference across behavioral states between the two groups. No similar studies were found that would allow for a comparison of the amplitude values in the neonatal period, which might be used as references to the protocol used.

The use of the Hearlab System equipment in this study, which provides automatic analysis, allowed the examiners greater reliability, in agreement with other studies that have also relied on such equipment, but with different populations[18,31,34]. The behavioral state of neonates did not have an influence on the responses obtained at the different frequencies investigated.

REM would be ideal for assessing the exogenous potentials in the neonatal period. One of the reasons derives from the fact that acetylcholine levels, an important neurotransmitter/hormone for maintaining wakefulness, are similar during REM sleep and wakefulness[35]. Furthermore, cell hyperpolarization would be greater during the early stages of sleep, thus leading to higher cortical-potential responses.

Although the results were satisfactory during the first month of life, light sleep (or REM sleep) time decreases with increasing age[25], which could compromise the results from the cortical auditory assessment in older children. Several studies have been conducted in children from three months; however, the CAEP results were obtained with the children in an alert state[13,19-21].

In general, the results of this study corroborate those obtained by other studies[22,27,32,36], in which cortical potentials were identified during sleep, albeit in different populations. The results are also in agreement with those of a recent study[37], in which researchers assessed newborns during light sleep and report that it is possible to obtain cortical responses in that behavioral state. Other researchers[22], in an animal model, describe that the hearing detection ability is preserved across the different stages of sleep, therefore suggesting that the primary sensory cortex activity is evoked by external acoustic stimuli, with little relation to the waking state. This statement apparently can be contemplated in humans, since this response are related to sensory perception of sounds[37]. These statements justifies the results of this study and supports the initial hypothesis that the assessment of cortical potentials can be carried out during light sleep in newborns.

The possibility of detecting cortical responses in this sleep stage allows the assessment of core functions to be accurate as early as in the neonatal period. The use of an automatic analysis device in this study ensured the reliability of cortical responses, which were not influenced by artifacts, which, in turn, could have become a bias when comparing the results. This fact permits CAEP to be used for assessing the central auditory maturation[12,37] and as an additional audiological diagnostic method as early as in the neonatal period.

In this study, only the P1i potential was analyzed because it is the most evident in the neonatal tracing, but the N2 component analysis is also interesting for understanding the maturational aspects of the central auditory structures, since in pediatric population P1 and N2 are the two most described components[38]. The components N1 and P2 are seen throughout the process maturational[38].

Thus, other studies with a larger sample and analysis of other cortical auditory evoked potentials, such as N2, may be useful to better understand the influence of behavioral states in the neonatal period. Perhaps, in this study, no difference between maturational states was identified due to the analysis of only the P1i component. These potentials help the clinician understand the maturational aspects of the auditory system and may be useful in the early identification of possible auditory changes throughout development.

CONCLUSION

The behavioral states of the neonates assessed in this study did not interfere with the achievement of the P1i potential, both in terms of latency and amplitude. This result contributes with the scientific literature that the P1i component can be visualized even in light sleep during the neonatal period, facilitating its application during this period.

REFERENCES

1. Wunderlich JL, Cone-Wesson BK. Maturation of CAEP in infants and children: A review. Hear Res. 2006;212(1-2):212-23. http://dx.doi.org/10.1016/j.heares.2005.11.008. PMid:16480841.

2. British Society of Audiology. Recommended procedure. Cortical Auditory Evoked Potential (CAEP) Testing. West Lothian: British Society of Audiology; 2016.

3. Cheour M, Martynova O, Nããtãnen R, Erkkola R, Sillanpaa M, Kero P, Raz A, Kaipio ML, Hiltunen J, Aaltonen O, Savela J, Hämäläinen H. Speech sounds learned by sleeping newborns. Nature. 2002;415(6872):599-600. http://dx.doi.org/10.1038/415599b. PMid:11832930.

4. Kushnerenko EV. Maturation of the cortical auditory event-related brain potentials in infancy [dissertation]. Finland: University of Helsinki; 2003.

5. Van Dun B, Dillon H, Seeto M. Estimating Hearing Thresholds in Hearing-Impaired Adults through Objective Detection of Cortical Auditory Evoked Potentials. J Am Acad Audiol. 2015;26(4):370-83. http://dx.doi.org/10.3766/jaaa.26.4.5. PMid:25879241.

6. Lightfoot G. Summary of the N1-P2 Cortical Auditory Evoked Potentials to Estimate the Auditory Threshold in Adults. Semin Hear. 2016;37(1):1-8. http://dx.doi.org/10.1055/s-0035-1570334. PMid:27587918.

7. Carter L, Golding M, Dillon H, Seymour J. The detection of infant cortical auditory evoked potentials (CAEPs) using statistical and visual detection techniques. J Am Acad Audiol. 2010;21(5):347-56. http://dx.doi.org/10.3766/jaaa.21.5.6. PMid:20569668.

8. Durante AS, Pucci B, Gudayol N, Freitas NR, Carvalho S, Almeida K, et al. Potencial Evocado Auditivo Cortical: avaliação da detecção da fala em adultos usuários de prótese auditiva. CoDAS. 2014;26(5):367-73. http://dx.doi.org/10.1590/2317-1782/20142013085. PMid:25388069.

9. Alvarenga KF, Vicente LC, Lopes RCF, Ventura LMP, Bevilacqua MC, Moret ALM. Desenvolvimento do potencial evocado auditivo cortical P1 em crianças com perda auditiva sensorioneural após o implante coclear: estudo longitudinal. CoDAS. 2013;25(6):521-6. http://dx.doi.org/10.1590/S2317-17822014000100004. PMid:24626977.

10. Sharma A, Cardon G, Henion K, Roland P. Cortical maturation and behavioral outcomes in children with auditory neuropathy spectrum disorder. Int J Audiol. 2011;50(2):98-106. http://dx.doi.org/10.3109/14992027.2010.542492. PMid:21265637.

11. Cardon G, Campbell J, Sharma A. Plasticity in the Developing Auditory Cortex: Evidence from Children with Sensorineural Hearing Loss and Auditory Neuropathy Spectrum Disorder. J Am Acad Audiol. 2012;23(6):396-411, quiz 495. http://dx.doi.org/10.3766/jaaa.23.6.3. PMid:22668761.

12. Didoné DD, Garcia MV, Silveira AF. Long latency auditory evoked potentials in term and premature infants. Int Arch Otorhinolaryngol. 2014;18(1):16-20. PMid:25992057.

13. Chang HW, Dillon H, Carter L, van Dun B, Young ST. The relationship between cortical auditory evoked potentials (CAEP) detection and estimated audibility in infants with sensorineural hearing loss. Int J Audiol. 2012;51(9):663-70. http://dx.doi.org/10.3109/14992027.2012.690076. PMid:22873205.

14. Almeqbel A. Speech evoked cortical auditory responses in children with normal hearing. S Afr J Commun Disord. 2013;60(1):38-43. http://dx.doi.org/10.4102/sajcd.v60i1.9. PMid:25158372.

15. Sharma A, Dorman F. Central auditory development in children with cochlear implants: Clinical implications. Adv Otorhinolaryngol. 2006;64:66-88. PMid:16891837.

16. Cardon G, Sharma A. Central Auditory Maturation and Behavioral Outcome in Children with Auditory Neuropathy Spectrum Disorder who Use Cochlear Implants. Int J Audiol. 2013;52(9):577-86. http://dx.doi.org/10.3109/14992027.2013.799786. PMid:23819618.

17. Sharma A, Martin K, Roland P, Bauer P, Sweeney MH, Gilley P, Dorman M. P1 latency as a biomarker for central auditory development in children with hearing impairment. J Am Acad Audiol. 2005;16(8):564-73. http://dx.doi.org/10.3766/jaaa.16.8.5. PMid:16295243.

18. Dun BV, Carter L, Dillon H. Sensitivity of cortical auditory evoked potential detection for hearing-impaired infants in response to short speech sounds. Audiol Res. 2012;2(1):65-76.

19. Purdy SC, Sharma M, Munro KJ, Morgan CLA. Stimulus level effects on speech-evoked obligatory cortical auditory evoked potentials in infants with normal hearing. Clin Neurophysiol. 2013;124(3):474-80. http://dx.doi.org/10.1016/j.clinph.2012.09.011. PMid:23117114.

20. Cone B, Whitaker R. Dynamics of infant cortical auditory evoked potentials (CAEPs) for tone and speech tokens. Int J Pediatr Otorhinolaryngol. 2013;77(7):1162-73. http://dx.doi.org/10.1016/j.ijporl.2013.04.030. PMid:23722003.

21. Cone BK. Infant cortical electrophysiology and perception of vowel contrast. Int J Psychophysiol. 2015;95(2):65-76. http://dx.doi.org/10.1016/j.ijpsycho.2014.06.002. PMid:24933411.

22. Nir Y, Vyazovskiy VV, Cirelli C, Banks MI, Tononi G. Auditory Responses and Stimulus-Specific Adaptation in Rat Auditory Cortex are Preserved Across NREM and REM Sleep. Cereb Cortex. 2015;25(5):1362-78. http://dx.doi.org/10.1093/cercor/bht328. PMid:24323498.

23. Shepherd A, Saunders K, McCulloch D. Effect of sleep state on the flash visual evoked potentials. A case study. Doc Ophthalmol. 1999;98(3):247-56. http://dx.doi.org/10.1023/A:1002471022790. PMid:10945444.

24. Steriade M, McCormick DA, Sejnowski TJ. Thalamocortical oscillations in the sleeping and aroused brain. Science. 1993;262(5134):679-85. http://dx.doi.org/10.1126/science.8235588. PMid:8235588.

25. Eisermann M, Kaminska A, Moutard ML, Soufflet C, Plouin P. Normal EEG in Childhood: From neonates to adolescents. Neurophysiol Clin. 2013;43(1):35-65. http://dx.doi.org/10.1016/j.neucli.2012.09.091. PMid:23290174.

26. De Weerd AW. Atlas of EEG in the first months of life. Amsterdam: Elsevier; 1995.

27. Suppiej A, Mento G, Zanardo V, Franzoi M, Battistella PA, Ermani M, Bisiacchi PS. Auditory processing during sleep in preterm infants: An event related potential study. Early Hum Dev. 2010;86(12):807-12. http://dx.doi.org/10.1016/j.earlhumdev.2010.09.002. PMid:20950966.

28. Joint Committee on Infant Hearing. Year 2007 Position statement: principles and guidelines for early hearing detection and intervention programs. Pediatrics. 2007;120(4):898-921. http://dx.doi.org/10.1542/peds.2007-2333. PMid:17908777.

29. World Health Organization. Born too soon: the global action report on preterm birth. Geneva: WHO; 2012.

30. Brazelton TB. Neonatal behavioral assessment scale. London: Heinemann Medical; 1973. (Clinics in developmental medicine series; no. 50).

31. Oliveira LS, Didoné DD, Durante AS. Automated cortical auditory evoked potentials threshold estimation in neonates. Rev Bras Otorrinolaringol (Engl Ed). 2018; (in press). http://dx.doi.org/10.1016/j.bjorl.2018.01.001. PMid:29409720.

32. Rector DM, Schei JL, Rojas MJ. Mechanisms underlying state dependent surface-evoked response patterns. Neuroscience. 2009;159(1):115-26. http://dx.doi.org/10.1016/j.neuroscience.2008.11.031. PMid:19154778.

33. Issa EB, Wang X. Altered neural responses to sounds in primate primary auditory cortex during slow-sleep. J Neurosci. 2011;31(8):2965-73. http://dx.doi.org/10.1523/JNEUROSCI.4920-10.2011. PMid:21414918.

34. King A, Carter L, Dun BV, Zhang V, Pearce W, Ching T. Australian Hearing Aided Cortical Evoked Potentials Protocols. Australia: HomeHEARLab; 2014.

35. Jones BE. From waking to sleeping: neuronal and chemical substrates. Trends Pharmacol Sci. 2005;26(11):578-86. http://dx.doi.org/10.1016/j.tips.2005.09.009. PMid:16183137.

36. Qi R, Li M, Ma Y, Chen N. State-Dependent Changes in Auditory Sensory Gating in Different Cortical Areas in Rats. PLoS One. 2015;10(4):1-12. http://dx.doi.org/10.1371/journal.pone.0126684. PMid:25928147.

37. Suppiej A, Cainelli E, Cappellari A, Ermani M, Sartori S, Bisiacchi PS. Neonatal Cortical Auditory Evoked Potentials Are Affected by Clinical Conditions Occurring in Early Prematurity. J Clin Neurophysiol. 2015;32(5):419-23. http://dx.doi.org/10.1097/WNP.0000000000000182. PMid:25923204.

38. Silva LAF, Magliaro FCL, Carvalho ACM, Matas CG. Maturação dos potenciais evocados auditivos de longa latência em crianças ouvintes: revisão sistemática. CoDAS. 2017;29(3):e20160107. http://dx.doi.org/10.1590/2317-1782/20172016107. PMid:28538829.