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Auditory cortical potential: using different types of speech stimuli in children

Potenciais corticais auditivos: uso de diferentes estímulos de fala em populações infantis

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ABSTRACT

Introduction: Auditory Evoked Potentials are electrical responses that occur in the central auditory pathways, resulting from acoustic stimulation. The use of speech stimuli to elicit the response of these potentials allows to understand information about speech coding and decoding in the central nervous system. **Purpose:** To compare the Long Latency Auditory Evoked Potential of two different speech stimuli. **Methods:** Thirty healthy school children of both genders, aged between 8 and 12 years, participated in the study. For the auditory evoked potentials, different speech stimuli were used for the auditory discrimination: Test 1 /ba/ x /da/ and Test 2 /pa/ x /da/. The stimuli were randomly presented: 20% infrequent and 80% frequent. The school children participated in an active auditory task and said [da] to identify the infrequent stimuli. The normality of the data was determined using the Shapiro-Wilk test. To compare the mean with Test 1 and Test 2, stimulation was performed using Student t test. **Results:** There was a significant difference in P3 latency in the right ear, P2 amplitude in the right ear and P3 amplitude in the left ear. Longer values occurred with stimulus /ba/ x /da/. **Conclusion:** The responses of long latency auditory evoked potentials vary depending on the stimulus and care in the analysis when using speech stimuli in the evaluation.

Keywords: Evoked Potentials, Auditory; Speech; Child development; Child; Event-Related Potentials, P300

RESUMO

Introdução: Os potenciais evocados auditivos são respostas elétricas que ocorrem nas vias auditivas centrais, resultantes de estimulação acústica. O uso de estímulos de fala para eliciar a resposta desses potenciais possibilita a compreensão de informações sobre codificação e decodificação da fala no sistema nervoso central. **Objetivo:** Comparar o resultado do potencial evocado auditivo de latência longa com dois diferentes estímulos de fala. **Métodos:** Participaram do estudo 30 escolares saudáveis, de ambos os sexos, com idade entre 8 e 12 anos. Para os potenciais evocados auditivos, foram utilizados dois diferentes estímulos de fala para a discriminação auditiva: Teste 1 /ba/ x /da/ e Teste 2 /pa/ x /da/. Os estímulos foram aleatoriamente apresentados, sendo 20% raros e 80% frequentes. Os escolares participaram de uma tarefa auditiva ativa e disseram [da] para identificar os estímulos raros. A normalidade dos dados foi determinada utilizando o teste de Shapiro-Wilk. Para comparar a média com o Teste 1 e Teste 2, foi realizada a estimulação t de Student. **Resultados:** Houve diferença significativa na latência P3 na orelha direita, amplitude P2 na orelha direita e amplitude P3 na orelha esquerda. Ocorreram valores mais longos com estímulo /ba/ x /da/. **Conclusão:** As respostas dos potenciais evocados auditivos de latência longa variam em função do estímulo e do cuidado em sua análise, quando se utilizam estímulos de fala na avaliação.

Palavras-chave: Potenciais Evocados Auditivos; Fala; Desenvolvimento infantil; Criança; Potencial Evocado P300

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INTRODUCTION

Auditory Evoked Potentials (AEP) are noninvasive auditory measures of auditory bioelectrical activity, from the surface of the scalp, after a sound stimulus. They are classified according to the time the auditory pathway takes to react to the stimulus, which may be of short, middle or long latency[1,2].

Long Latency Auditory Evoked Potentials (LLAEP) are generated in the auditory cortex region, mainly in the thalamo-cortical and cortico-cortical auditory pathways, primary auditory cortex and associative cortical areas[3,4].

LLAEP recording and analysis can be elicited through different types of stimulus. The most used are pure tone and tone burst, but the literature[5,6] has demonstrated the use of speech stimuli to elicit the response of these potentials, emphasizing the possibility of analyzing complex signals in the auditory cortex through these measures[7,8].

Auditory potentials, when generated by speech stimuli, seek to understand the underlying processes of speech coding and decoding in the central auditory system. In practice, the use of speech stimuli in LLAEP examination helps to evaluate the auditory processing of acoustic and linguistic information. In addition, it sensitizes the study of the neural bases of speech detection and discrimination[9,10].

LLAEP are recorded and analyzed by a sequence of peaks with positive-negative polarity, i.e., P1, N1, P2, N2 and P3. In the literature, authors reported that the components P1, N1, P2 and N2, when generated by speech stimuli, vary from 100 ms to 300 ms[11,12].

The P1-N1-P2 complex signals the neural processing of the acoustic signal at the level of the auditory cortex and can be elicited in response to tonal and speech stimuli, presenting the syllable /da/. The presence of the P1-N1-P2 complex suggests that the speech was coded at the level of the auditory cortex and the absence of response is consistent with some imprecision in this process[6,13,14,15].

Some authors have carried out studies on the influence of vowel and consonant speech stimuli on long-latency auditory evoked potentials in children and adults with normal hearing, and could observe that there was influence on the measurements of the components P1, N1, N2 and P3, due to the level of complexity of the speech stimulus[16,17]. Therefore, the hypothesis of this study was to understand how such stimuli influence the generation of auditory evoked potentials and their components.

It is known that, between 4 and 5 years of age, speech perception is improved and that this ability is established until the age of 11 or 12, when speech perception maturation occurs. Therefore, because the maturational process is not complete, variations in the response in relation to the acoustic complexity of the speech stimulus and difficulty in its processing are expected[13,14,15,16].

Authors emphasized that using these potentials is important when elicited by speech stimuli, since they allow the monitoring of auditory development in normal children and in children at risk of developing communication disorders and language impairments[17]. This issue needs further investigation, but it is current and extremely important and may result in the determination of normality standards, in addition to help in the interpretation of these measures in different clinical populations.

Since the speech stimulus is a complex signal and its presence signals speech processing in the cortex, this study aimed to compare the results of Long Latency Auditory Evoked Potential with two different speech stimuli.

METHODS

This is a cross-sectional study with a quantitative and qualitative design. Thirty healthy school children of both sexes, aged 8 to 12 years, participated in the study. The project was analyzed and approved by the Research Ethics Committee of the *Universidade Estadual Paulista "Júlio de Mesquita Filho"*, process number 1002/2014. To select the participants, the following inclusion criteria were established: age between 8 and 12 years; absence of complaints or current history of affections in the auditory system; absence of psychiatric, cognitive, physical or motor impairment; absence of changes in oral or written language and satisfactory performance in Portuguese and Mathematics for at least two consecutive bimonths, identified by the teacher.

To select the sample, audiological history was performed, basic audiological evaluation, composed of inspection of the external auditory meatus, tonal audiometry and imitanciometry.

The materials used in this research were: Heine® otoscope, GSI 61 Grason-Stadler® two-channel audiometer, GSI-33 middle ear analyzer and Biologic's Evoked Potential System (EP)® two-channel auditory evoked potential equipment.

After the selection of the sample, all those responsible for the research participants were informed about the content and purpose of this research and after they signed the Informed Consent Term, the tests were performed. As an initial procedure, audiological anamnesis was performed, aiming to investigate the history of the general and auditory health of the subjects. Then, audiological evaluation was performed: tonal audiometry, frequencies from 250 Hz to 8000 Hz with air conduction headphones and from 500 Hz to 4000 Hz with bone conduction headphones, tympanometry, ipsilateral and contralateral reflex checks, at frequencies of 500 Hz to 4000 Hz. After confirming the normality of the peripheral auditory system through the procedures described above, indicating normal auditory acuity (thresholds less than or equal to 25 dBHL)[18], type A tympanogram, indicating normal mobility of the tympano-ossicular system[19,20] and ipsilateral and contralateral reflexes present, research of the LLAEP was carried out.

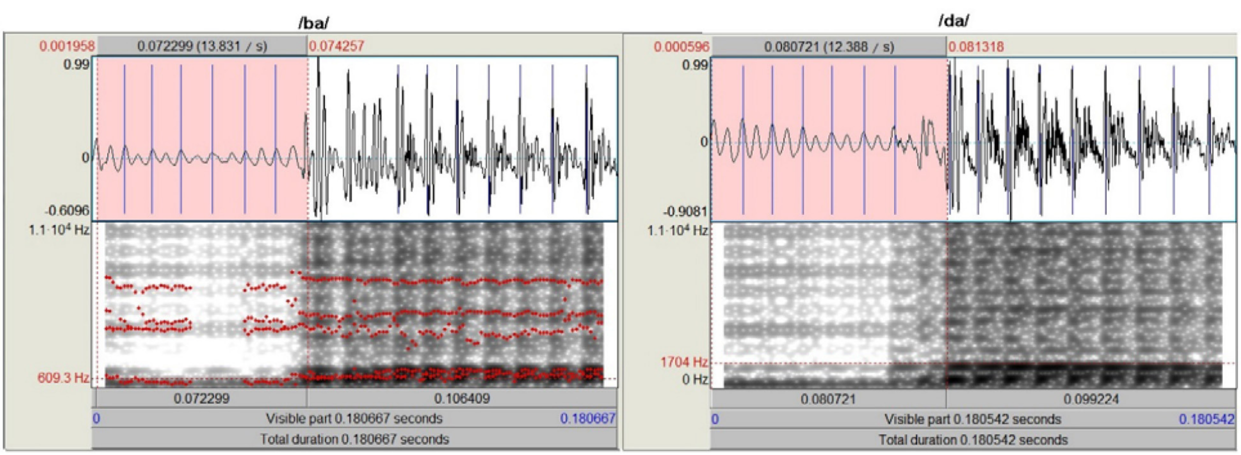
For the LLAEP recording, the subjects were accommodated in an acoustically treated and temperature controlled room at 24 ºC, positioned in a reclining chair and guided to remain relaxed and with their eyes open. The electrodes were fixed with microporous adhesive tape, after cleaning the skin with abrasive paste, using electrolytic paste, for better electrical conductivity. The impedance of each electrode did not exceed 5 Kohms and did not exceed 2 Kohms, between the impedances of the electrodes[1].

The natural speech stimuli were of fluent male voices, lasting 180 ms, extracted from the second syllable, during the emission [dada] in which the formants F1, F2 and F3 were obtained in their initial and stable portion, at an intensity of 70 dB NA Pe. These stimuli were developed in *Laboratório de Linguística do Instituto de Estudos de Linguagem* of *Universidade Estadual de Campinas*, recorded in Praat® (Version 4.2.31), 48 kHz and later recorded in CD, for insertion in Wave format for the Biologic Navigator® software.

For measuring the potentials, different stimuli and contrasts were used: /ba/ x /da/ and /p/ x /da/ and two tests were performed. In Test 1 (Figure 1), the syllable /ba/ was the standard stimulus (total syllable duration: 180 ms; voice onset time - VOT: - 70 ms; formant transition between consonant-vowel - CV: F1: 609.3 Hz; F2: 1269 Hz), and the syllable /da/, the rare stimulus (total syllable duration: 180 ms, voice onset time - VOT: - 79 ms, formant transition between consonant-vowel - CV: F1: 608 Hz; F2: 1704 Hz). In Test 2 (Figure 2), the syllable /pa/ was the standard stimulus (total syllable duration: 123 ms, voice onset time - VOT: 15 ms, formant transition between the consonant-vowel - CV: F1: 663, and the syllable /da/, the rare stimulus (total syllable duration: 180 ms, voice onset time - VOT: - 79 ms, formant transition between consonant-vowel - CV: F1: 608 Hz: F2: 1704 Hz).

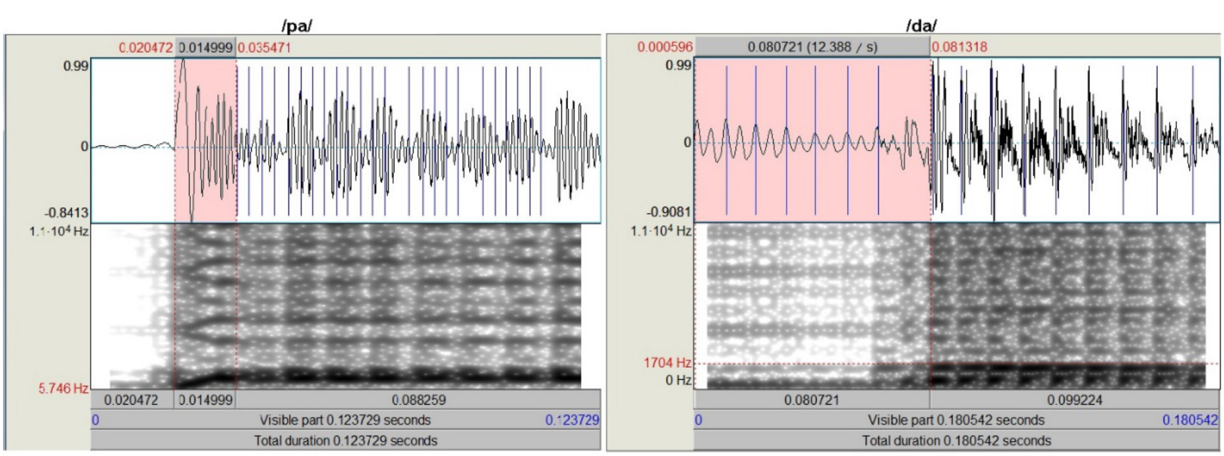
These stimuli were chosen to guarantee the evaluation of the perception of distinct acoustic properties during the auditory discrimination task.

The stimuli were presented randomly, at the proportion of 20% rare stimuli, out of a total of 200 stimuli, assuring the sum of 40 minimal responses of rare stimulus, necessary for the recording of artifact-free LLAEP[21]. The data were recorded in a window of 500 ms, with bandpass filtering of 1-30 Hz, amplification of 50,000 × and monoaural stimulus, stimulation rate at 1.9 stimuli/second, with alternating polarity.



Subtitle: /ba/ = standard stimulus; /da/ = rare stimulus

Figure 1. Characteristics of acoustic stimuli - Test 1



Subtitle: /pa/ = standard stimulus; /da/ = rare stimulus

Figure 2. Characteristics of acoustic stimuli - Test 2

The responses were recorded with the electrodes positioned at Cz and Fz, with reference to the ears A1 and A2 (left and right ears), and ground at Fpz (forehead), alternating the right and left ear stimulations.

For recording the LLAEP, the patients performed an active task, paying attention and discriminating the stimuli, naming them as [da].

The latency and amplitude values of P1, N1, P2, N2 components were marked following criteria established in the literature. This complex was identified at the highest peak, in sequence, in the negative - positive - negative polarities, respectively, between 60 ms and 300 ms[22], and P3 was marked after the N1 - P2 - N2 complex, between 220 ms and 400 ms[1]. The cortical components were marked in rare waves and there was no subtraction of the waves.

The normality of the data was determined using the Shapiro-Wilk test. For the comparison between the measurements of Test 1 and Test 2, Student's t-test was performed. The software used for the analysis was BioEstat version 5.3.

RESULTS

The descriptive analysis of mean and standard deviation and inferential analysis of LLAEP latencies of components P1, N1, P2, N2 and P3 with speech stimuli /pa/ x /da/ and /ba/ x /da/ are presented in Table 1. We verified statistical significance in P3 latency when stimulated in the right ear.

The results of LLAEP - P1, N1, P2, N2, P3 amplitudes were analyzed through mean and standard deviation values, in addition to the comparison among the speech /pa/ x /da/ and /ba/ x /da/, in right and left measures. There was an increase in the amplitude of P2 with stimulus /ba/ x /da/ in the right ear and P3 in the left ear (Table 2).

When comparing the obtained means of latency and amplitude of the components, with different stimuli between the ears, it was verified that there was no statistical difference (with values between 0.09 and 0.97).

DISCUSSION

LLAEP is one of the measures used to investigate the central auditory processing and cortical abilities of attention, recognition and auditory discrimination, involved in information processing, with important application in children under conditions of normal and deviant auditory development[7,23].

The mean latency intervals for P1, N1, P2 and N2 components ranged from 87 ms to 221 ms for children in the studied age range, according to the reference of other studies that used complex stimuli[11,12,24].

The morphology analysis of LLAEP P1-N1-P2 complex, regarding speech stimuli, expresses exogenous responses related to the acoustic characteristics of sound processing[1]. The use of different speech stimuli with phonemic contrasts expresses the complexity of acoustic information at the level of the cortex and throughout the maturation of the auditory system[6,12]. In children older than 6 years, the response of the exogenous components of LLAEP is similar to that of adults, which justifies the choice of the population of this study[12].

The variation of LLAEP response to P2 amplitude, increased with stimulus /ba/ x /da/ in the right ear, is directly related to the perception of the physical and temporal characteristics of the stimulus. This component reflects the necessary attention for the performance of an auditory discrimination task[25].

In a deeper analysis, consonant perception occurs through transient acoustic events, which can be perceived separately[25], and through a detailed analysis of the phoneme

Table 1. Comparison of latencies of P1, N1, P2, N2 and P3 waves for different speech stimuli

Components	Stimuli								p-value
	/pa/x/da/				/ba/x/da/				
	Mean	SD	CI 95%		Mean	SD	CI 95%		
			IT	ST			IT	ST	
P1 RE	71.66	23.10	63.19	80.14	71.90	19.35	64.80	79	0.96
N1 RE	115.42	0.06	107.69	123.15	109.28	24.82	100.17	118.38	0.32
P2 RE	156.83	30.24	145.73	167.92	155.18	31.82	143.51	166.86	0.68
N2 RE	221.93	30.70	210.67	233.19	228.69	30.91	217.35	240.03	0.59
P3 RE	301.29	36.68	287.84	314.75	316.77	36.95	303.22	330.33	0.05*
P1 LE	77.98	27.01	68.07	87.89	66.66	29.73	55.75	77.57	0.19
N1 LE	121.20	37.44	107.46	134.93	118.71	38.71	104.51	132.91	0.84
P2 LE	157.42	49.28	139.34	175.50	165.90	42.68	150.24	181.56	0.34
N2 LE	223.95	37.57	210.17	237.74	227.58	34.25	215.02	240.15	0.35
P3 LE	304.18	33.20	260.33	316.36	304.11	38.47	253.04	318.23	0.99

*Significant values ($p \leq 0.05$) – t Test coupled/Wilcoxon

Subtitle: RE = right ear; LE = left ear; SD = standard deviation; CI 95% = confidence interval; IT = inferior threshold; ST = superior threshold

Table 2. Comparison of amplitudes of P1, N1, P2, N2 and P3 waves for different speech stimuli

Components	Stimuli								p-value
	/pa/x/da/				/ba/x/da/				
	Mean	SD	CI 95%		Mean	SD	CI 95%		
			IT	ST			IT	ST	
P1 RE	2.91	2.62	1.95	3.87	3.15	2.37	2.28	4.02	0.64
N1 RE	-4.45	3.67	-5.80	-3.10	-3.5	3.82	-4.94	-2.13	0.30
P2 RE	1.15	3.61	-0.17	2.48	2.63	3.45	1.36	3.90	0.03*
N2 RE	-7.29	3.44	-8.55	-6.03	-7.83	2.81	-8.86	-6.80	0.50
P3 RE	5.44	4.20	3.90	6.99	4.013	3.61	2.68	5.33	0.08
P1 LE	2.96	3.00	1.86	4.07	3.93	3.27	2.73	5.13	0.22
N1 LE	-4.00	3.64	-5.33	-2.66	-4.15	3.90	-5.59	-2.72	0.87
P2 LE	1.90	2.90	0.83	2.96	1.23	2.63	0.26	2.20	0.17
N2 LE	-7.69	4.37	-9.29	-6.09	-7.81	2.75	-8.82	-6.80	0.88
P3 LE	5.48	4.46	3.84	7.12	2.91	3.60	1.59	4.23	0.01**

*Significant values (p≤0.05) – t Teste coupled /**Wilcoxon

Subtitle: RE = right ear; LE = left ear; SD = standard deviation; CI 95% = confidence interval; IT = inferior threshold; ST = superior threshold

characteristics[26]. When the speech stimuli /ba/ x /da/ are employed, the perception involves distinct acoustic properties, related to the articulation point, as a single "anterior" articulatory phonemic clue, for identification. Therefore, recognition becomes more complex and the speed and quality of auditory processing can be affected. Thus, the response latency of the late component of LLAEP observed in this research can be justified by the complexity of the speech stimulus discrimination in Test 1[6].

The increased amplitude for the P3 component, in this study, suggests changes in the synaptic magnitude[27], compatible with the greater demand for electrical activation, necessary for the distinction between /ba/ x /da/.

When comparing P3 latencies with vowel and speech stimuli, in other studies, it was possible to observe that the speech stimulus influenced the P3 component. In studies, the degree of difficulty in discriminating this contrast was reported to be greater than in vowel contrast, which strengthens the assertion of this study that the greater the complexity of the stimulus, the greater the variation of the LLAEP components[28,29].

Some questions about the LLAEP measurement with speech stimuli should be considered. The study replication in this theme requires methodological care of acoustic recording and analysis and standardization of the test stimuli. In addition, comparative analyzes of the latency and amplitude values are somewhat restricted, since the type of stimulus used significantly influences the LLAEP results, especially when complex stimuli are employed.

CONCLUSION

The responses of the long latency auditory evoked potentials with speech stimuli vary according to the stimulus characteristic and their use in the speech-language clinical populations must be carefully considered in the analysis and interpretation of the results.

REFERENCES

1. Hall, J. Handbook of auditory evoked responses. Boston: Allyn & Bacon; 2006.
2. Ferraro J, Durrant J. Auditory evoked potentials: overview and basic principles. In: Katz J, editor. Handbook of clinical audiology. 4th ed. Baltimore: Williams; 1994. p. 317-38.
3. Woods DL, Clayworth C, Knight L, Simpson G, Naeser M. Generators of middle and long-latency auditory evoked potentials: implications for studies of patients with temporal lobe lesions. Electroencephalogr Clin Neurophysiol. 1987;68(2):132-48.
4. Kraus N, Nicol T. Aggregate neural responses to speech sounds in the central auditory system. Speech Commun. 2003;41(1):35-47.
5. Martin BA, Tremblay KL, Korczak P. Speech evoked potentials: from the laboratory to the clinic. Ear Hear. 2008;29(3):285-313. https://doi.org/10.1097/AUD.0b013e3181662c0e
6. Alvarenga KF, Vicente LC, Lopes RCF, Silva RA, Banhara MR, Lopes AC et al. Influência dos contrastes de fala nos potenciais evocados auditivos corticais. Braz J Otorhinolaryngol. 2013;79(3):336-41. https://doi.org/10.5935/1808-8694.20130059
7. Alvarenga KF, Amorim RB, Agostinho-Pesse RS, Costa OA, Nascimento LT, Bevilacqua MC. Speech perception and cortical auditory evoked potentials in cochlear implant users with auditory neuropathy spectrum disorders. Int J Pediatr Otorhinolaryngol. 2012;76(9):1332-8. https://doi.org/10.1016/j.ijporl.2012.06.001
8. Ponton CW, Don M, Eggermont JJ, Waring MD, Kwong B, Masuda A. Auditory system plasticity in children after long periods of complete deafness. Neuroreport. 1996;8(1):61-5.

9. Korczak PA, Kurtzberg D, Stapells DR. Effects of sensorineural hearing loss and personal hearing AIDS on cortical event-related potential and behavioral measures of speech-sound processing. Ear Hear. 2005;26(2):165-85.
10. Sharma A, Nash AA, Dorman M. Cortical development, plasticity and re-organization in children with cochlear implants. J Commun Disord. 2009;42(4):272-9. https://doi.org/10.1016/j.jcomdis.2009.03.003
11. Shafer VL, Yu YH, Wagner M. Maturation of cortical auditory evoked potentials (CAEPs) to speech recorded from frontocentral and temporal sites: three months to eight years of age. Int J Psychophysiol. 2015;95(2):77-93. https://doi.org/10.1016/j.ijpsycho.2014.08.1390
12. Carpenter AL, Shahin AJ. Development of the N1–P2 auditory evoked response to amplitude rise time and rate of formant transition of speech sounds. Neurosci Lett.. 2013;544:56-61. https://doi.org/10.1016/j.neulet.2013.03.041.
13. Wunderlich JL, Cone-Wesson BK. Maturation of CAEP in infants and children: a review. Hear Res. 2006;212(1-2):212-23. https://doi.org/10.1016/j.heares.2005.11.008
14. Abercrombie D. Elements of general phonetics. Cambridge: Cambridge University Press; 1967.
15. Poeppel D, Marantz A. Cognitive neuroscience of speech sound processing: image language and brain. Cambridge: MIT Press; 2000.
16. 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. https://doi.org/10.1016/j.ijporl.2013.04.030
17. Cone BK. Infant cortical electrophysiology and perception of vowel contrasts. Int J Psychophysiol. 2015;95(2):65-76. https://doi.org/10.1016/j.ijpsycho.2014.06.002
18. Loyd LL, Kaplan H. Audiometric interpretation: a manual o basic audiometry. Baltimore: University Park Press;1978.
19. Jerger J. Clinical experience with impedance audiometry. Arch Otolaryngol.1970;92(4):311-24.
20. Junqueira CAO, Colafêmina JF. Investigação da estabilidade inter e intra-examinador na identificação do P300 auditivo: análise de erros. Rev Bras Otorrinolaringol. 2002;68(4):468-78. https://doi.org/10.1590/S0034-72992002000400004
21. Polich J, Margala C. P300 and probability: comparison of oddball and single-stimulus paradigms. Int J Psychophysiol. 1997;25(2):169-176. https://doi.org/10.1016/S0167-8760(96)00742-8
22. Sharma A, Kraus N, McGee T, Nicol T. Developmental changes in P1 and N1 auditory responses elicited by consonant-vowel syllables. Clin Neurophysiol.1997;104(6):540-5.
23. Regaçone FS, Gução BCA, Frizzo FCA. Eletrofisiologia: perspectivas atuais de sua aplicação clínica em Fonoaudiologia. Verba Volant. 2013;4(1):1-20.
24. Laufer I, Negishi M, Constable RT. Comparator and non-comparator mechanisms of change detection in the context of speech: an ERP study. Neuroimage. 2009;44(2):546-62. https://doi.org/10.1016/j.neuroimage.2008.09.010
25. Ordunã I, Liu EH, Church BA, Eddins AC, Mercado E. Evoked-potential changes following discrimination learning involving complex sounds. Clin Neurophysiol. 2012;123(4):711-9. https://doi.org/10.1016/j.clinph.2011.08.019
26. Burgess SR, Lonigan CJ. Bidirectional relations of phonological sensitivity and prereading abilities: evidence from a preschool sample. J Exp Child Psychol. 1998;70(2):117-41. https://doi.org/10.1006/jecp.1998.2450
27. Vaughan HGJR, Ritter W. The sources of auditory evoked responses recorded from the human scalp. Electroencephalogr Clin Neurophysiol. 1970;28(4):360-7. https://doi.org/10.1016/0013-4694(70)90228-2
28. Bennett KO, Billings CJ, Molis MR, Leek MR. Neural encoding and perception of speech signals in informational masking. Ear Hear. 2012;33(2):231-8. https://doi.org/10.1097/AUD.0b013e31823173fd
29. Purdy SC, Kelly AS, Davies MG. Auditory brainstem response, middle latency response, and late cortical evoked potentials in children with learning disabilities. J Am Acad Audiol. 2002;13(7):367-82.