CoDAS
ISSN 2317-1782 (Online version)

Original Article
Artigo Original

Alessandra Spada Durante[1]
Suenia de Jesus Oliveira[1]

Frequency-following response (FFR) with speech stimulus in normal-hearing young adults

Frequency-following response (FFR) com estímulo de fala em jovens adultos normo-ouvintes

Keywords

Hearing
Electrophysiology
Cochlear Nerve
Brainstem Auditory Evoked Potentials
Speech Perception

ABSTRACT

Purpose: Analyze the slope, latency and amplitude values of the waveforms V, A, C, D, E, F and O from Frequency-following Response (FFR) with speech stimulus in normal-hearing adults based on a recent international reference study. **Method:** Eleven normal-hearing adults aged 18-30 years, without hearing complaints, were evaluated in this study using an Intelligent Hearing Systems device. The speech stimulus /da/ was presented to the right ear via insertion phone and the responses were captured by electrodes placed on the vertex, right mastoid bone, and forehead (ground). **Results:** The descriptive latency values of the components were V 6.50, A 7.87, C 17.74, D 22.77, E 32.07, F 40.03 and O 48.07 ms. The mean amplitude measures of the waves were V 0.17, A -0.12, C -0.14, D -0.14, E -0.20, F -0.22 and O -0.14 µV. The mean slope value was 0.23. Comparison with an international study, Krizman et al. (2012), showed that most of the results are within positive and negative standard deviation values for the assessed age group for slope, latency and amplitude. **Conclusion:** The electrophysiological measures obtained from Frequency-following Response using the speech stimulus /da/ in normal-hearing adults without hearing complaints showed slope, latency and amplitude values of all FFR components within the normality standard described in the international literature.

Descritores

Audição
Eletrofisiologia
Nervo Coclear
Potenciais Evocados Auditivos do Tronco Encefálico
Percepção da Fala

RESUMO

Objetivo: Analisar o *slope* e as latências e amplitudes das ondas V, A, C, D, E, F e da *Frequency-Following Response*, com estímulo de fala, em adultos com audição normal, tendo como base referência internacional. **Método:** Onze adultos normo- ouvintes com idade entre 18 e 30 anos, sem queixas auditivas, foram avaliados na pesquisa. O equipamento utilizado foi o *Intelligent Hearing System*. O estímulo de fala /da/ foi apresentado por meio de fone de inserção na orelha direita e a resposta foi captada por meio de eletrodos posicionados no vértex, na mastoide direita e eletrodo terra na fronte. **Resultados:** Os valores descritivos de latência dos componentes foram: V 6,50, A 7,87, C 17,74, D 22,77, E 32,07, F 40,03 e O 48,07 ms. As médias de amplitude foram V 0,17, A -0,12, C -0,14, D -0,14, E -0,20, F -0,22 e O -0,14 µV. A média do valor do *slope* encontrada foi 0,23. Na comparação com estudo de referência internacional, Krizman et al. (2012) mostraram que a maioria dos resultados se encontra dentro de um desvio padrão positivo e negativo para a faixa etária estudada tanto para o *slope* quanto para as latências e amplitudes. **Conclusão:** A resposta eletrofisiológica da *Frequency Following Response*, utilizando o estímulo de fala /da/, em adultos com audição normal e sem queixas auditivas, apresentou valores de *slope* e de latência e amplitude de todos os componentes dentro do padrão de normalidade apresentado pela literatura internacional.

Correspondence address:
Alessandra Spada Durante
Rua Dr Cesario Motta Junior, 61 - 10 andar, Vila Buarque, São Paulo (SP), Brasil, CEP 01221 020.
Fone: (11) 33677785.
E-mail: alessandra.durante@fcmsantacasasp.edu.br

Received: February 15, 2019.

Accepted: July 26, 2019.

Study conducted at the Curso de Fonoaudiologia, Faculdade de Ciências Médicas da Santa Casa de São Paulo – FCMSCSP - São Paulo (SP), Brasil.

[1] Curso de Fonoaudiologia da Faculdade de Medicina, Faculdade de Ciências Médicas da Santa Casa de São Paulo – FCMSCSP - São Paulo (SP), Brasil.

Conflict of interests: Nothing to declare.
Financial support: Nothing to declare.

INTRODUÇÃO

Frequency-following Response (FFR) with speech stimulus, formerly known as Brainstem Auditory Evoked Potential (BAEP) with speech stimulus, has currently been studied with the purpose of characterizing auditory pathway responses to more complex sounds than the click, which is the stimulus commonly used in clinical practice to assess the integrity of the auditory pathway[1]. One of the advantages of this examination is that it enables observation of the auditory system behavior in relation to speech stimulus, which would not be possible using stimuli such as the click due to the non-linearity of the auditory system[2]. The FFR reflects the temporal and spectral characteristics of the stimulus, as the response peaks reflect their acoustic landmarks and occur ~6 to 8ms after the corresponding stimulus landmark. This latency is consistent with neural transmission time between the cochlea and the rostral brainstem[3].

The FFR has seven characteristic peaks known as V, A, C, D, E, F, and O. The stimulus used is the stop-consonant speech syllable /da/ and the response is divided into transient and sustained portions, with the first formed by the onset response and the latter by the FFR. The onset portion is composed of waveforms V, A and C, which correspond to the plosive consonant /d/ and the consonant-to-vowel transition /a/. The FFR concerns the fundamental frequency (F_o) and the formant transition of the consonant-vowel harmonic structure[1].

With the aim to compare patients with Central Auditory Processing Disorder (CAPD) with individuals with typical development (TD), an important national study revealed no differences between the groups using BAEP with click stimulus. A statistically significant difference was observed between the groups using speech stimulus (syllable /da/), which suggests that this type of stimulus is more sensitive in identifying changes in auditory processing at the brainstem level[4].

Another aspect that can be evidenced by the FFR is the impact of auditory training on children with CAPD, which revealed significant changes between the pre- and post-intervention results, suggesting that there is need to reflect on the plasticity of neural activity in the brainstem for speech stimuli[5].

However, there are few studies analyzing all FFR components. In view of the positive results obtained with the use of FFR reported in recent studies, it is essential to conduct a national study with normal-hearing individuals foreseeing the wide applicability of this examination in clinical practice. Thus, the present study aimed to analyze electrophysiological measures obtained from FFR with speech stimulus in normal-hearing adults based on a recent international reference.

METHOD

This is a prospective, descriptive, cross-sectional, quantitative study whose procedures were approved by the Research Ethics Committee of the aforementioned Institution under protocol number CAEE 59539016.1.0000.5479. All participants signed an Informed Consent Form (ICF) prior to study commencement.

Study sample

Sample calculation was performed at the Statistics Service considering a 95% confidence interval and an error of 3%, and a sample size of 10 individuals was determined.

Thus, after application of the inclusion and exclusion criteria, 11 normal-hearing female adult students of the Institution aged 18-28.6 years were included in the study.

Inclusion and Exclusion Criteria

Inclusion criteria

The inclusion criteria comprised young female adults attending higher education, aged 18-30 years, without hearing complaints, with hearing thresholds ≤25 dBHL at the frequencies between 250 and 8000 Hz in both ears, immittance measure with probe tone of 226 Hz for type A tympanometric curve, and presence of ipsilateral and contralateral acoustic reflexes.

Exclusion criteria

Individuals who did not conclude the examination for technical reasons, presented artifacts above the limit of 20% of the stimulus and/or high noise with tracings without good reproducibility were excluded from the survey.

Procedures

Electrophysiological measures from Frequency-following Response (FFR) with speech stimulus were taken in an acoustically treated room at the Speech-language Pathology Clinic of the *Irmandade da Santa Casa de Misericórdia de São Paulo* (ISCMSP) using an Intelligent Hearing Systems (IHS) device.

Prior to placing the electrodes, the skin was cleaned with abrasive paste and gauze to reduce the skin impedance so that the equipment impedance measure varied from 1 to 3 kΩ, and electrolytic paste was used to improve electrical conductivity. The electrodes were placed at the following positions: vertex, (active; noninverting/positive), right mastoid bone (reference; inverting/negative), and forehead (ground). After placing the electrodes as previously described and inserting the phone in the right ear, each individual was instructed to sit comfortably in an armchair in order to avoid artifacts caused by tension and/or movement.

Frequency-following Response (FFR) protocol

Two 3000-stimulus scans of the stop-consonant speech syllable /da/ were performed at 80 dBHL, presented at a rate of 10.9 Hz, with duration of 40 ms, and an analysis window of 60 ms. The line filter was activated and the responses were filtered with an additional type 19 filter with bandwidth from 100 to 2000 Hz, with a limit of 20% of presence of artifact[6].

The tracings generated by the two stimulus presentations were added and the resulting tracing was used to mark the V, A, C, D, E, F and O components and to analyze their latency and amplitude values, as it can be observed in the examination result model (Figure 1).

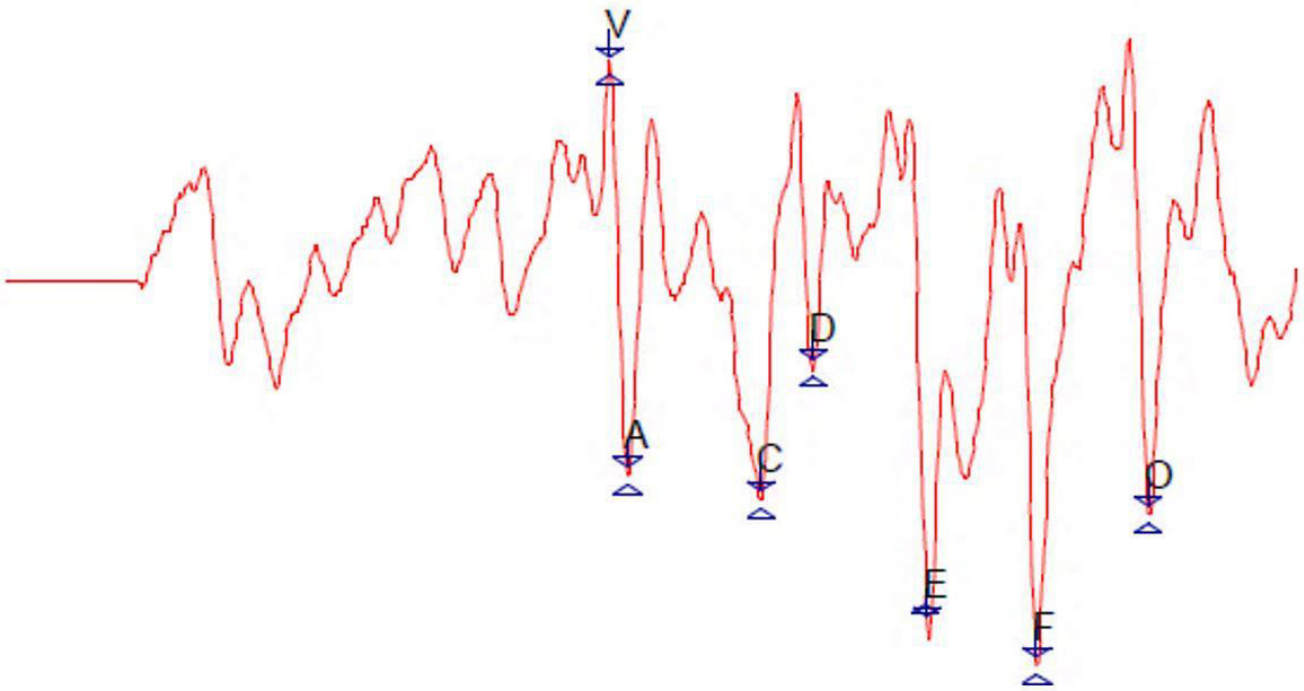

Figure 1. Result model of the FFR with speech stimulus /da/. This stimulus evokes seven characteristic response peaks termed V, A, C, D, E, F, and O

As this is an examination whose analysis is subjective, three speech-language pathologists who are knowledgeable in FFR were invited to be judges. They individually measured the components of the tracings resulting from the 11 individuals assessed, and their results were concordant.

Subsequently, the slope value of the VA complex was calculated, which is the VA complex amplitude/duration ratio (VA amplitude/VA duration)[7].

Data analysis

Latency and peak amplitude data for each individual were tabulated in Microsoft Office Excel® spreadsheet and descriptive analysis was performed using the SPSS 13 software.

RESULTS

This study analyzed the measures, obtained from the Frequency-following Response examination using the stop-consonant syllable /da/ as speech stimulus of 11 young female normal-hearing adults without hearing complaints attending higher education. The mean age of the sample was 21.0 years (minimum of 18.6 and maximum of 28.6 years).The FFR protocol was carried out without difficulties, and collection lasted roughly 20 min, ranging from 15 (minimum time) to 25 min (maximum time).

Table 1 shows the descriptive latency values of the FFR components V, A, C, D, E, F and O as well as the slope value. These components were observed in 100% of the sample.

Table 1. Descriptive latency (ms) values of the FFR components

Latency (Components)	Mean	Median	SD	Minimum	Maximum
V	6.50	6.50	0.19	6.13	6.88
A	7.87	7.88	0.19	7.63	8.25
C	17.74	18.00	0.94	15.50	18.63
D	22.77	22.75	0.45	22.25	23.75
E	32.07	31.88	0.84	31.00	33.63
F	40.03	39.88	0.48	39.50	40.88
O	48.07	48.13	0.38	47.25	48.50
Slope (ms/μV)	0.23	0.18	0.09	0.15	0.39

Captions: SD = standard deviation

The descriptive amplitude measures of the waves V, A, C, D, E, F and O are presented in Table 2.

Table 2. Descriptive amplitude (μV) values of the FFR components

Amplitude (Components)	Mean	SD	Minimum	Maximum
V	0.17	0.09	0.08	0.39
A	-0.12	0.05	-0.25	-0.07
C	-0.14	0.14	-0.54	-0.06
D	-0.14	0.11	-0.40	-0.04
E	-0.20	0.05	-0.28	-0.11
F	-0.22	0.07	-0.37	-0.11
O	-0.14	0.09	-0.38	-0.04

Captions: SD = standard deviation

Chart 1. Comparison between the mean latency (ms) values of the FFR components of the present study and those of the international reference[3]

Latency (ms)	Comp.	Mean	SD	+1 SD	-1 SD	+1.5 SD	-1.5 SD	+2 SD	-2 SD
Study	V	6.50	0.19	6.70	6.31	6.79	6.21	6.89	6.12
Reference	V	6.60	0.24	6.84	6.36	6.96	6.24	7.08	6.12
Study	A	7.87	0.19	8.06	7.68	8.15	7.58	8.24	7.49
Reference	A	7.54	0.34	7.88	7.20	8.05	7.03	8.22	6.86
Study	C	17.74	0.94	18.69	16.80	19.16	16.32	19.63	15.85
Reference	C	18.63	0.67	19.30	17.96	19.64	17.63	19.97	17.29
Study	D	22.77	0.45	23.23	22.32	23.45	22.09	23.68	21.87
Reference	D	22.75	0.81	23.56	21.94	23.97	21.54	24.37	21.13
Study	E	32.07	0.84	32.92	31.23	33.34	30.80	33.76	30.38
Reference	E	31.04	0.62	31.66	30.42	31.97	30.11	32.28	29.80
Study	F	40.03	0.48	40.50	39.55	40.74	39.31	40.98	39.07
Reference	F	39.50	0.45	39.95	39.05	40.18	38.83	40.40	38.60
Study	O	48.07	0.38	48.45	47.69	48.64	47.50	48.83	47.31
Reference	O	48.25	0.36	48.61	47.89	48.79	47.71	48.97	47.53
Study	Slope*	0.23	0.09	0.32	0.14	0.37	0.10	0.41	0.05
Reference	Slope*	0.39	0.16	0.55	0.23	0.63	0.15	0.71	0.07

Captions: SD = standard deviation; Comp. = component.

* in (ms/μV).

Chart 2. Comparison between the mean amplitude (μV) values of the FFR components of the present study and those of the international reference[3]

Amplitude (μV)	Comp.	Mean	SD	+1 SD	-1 SD	+1.5 SD	-1.5 SD
Study	V	0.17	0.09	0.26	0.08	0.31	0.04
Reference	V	0.13	0.07	0.20	0.06	0.24	0.03
Study	A	-0.12	0.05	-0.07	-0.17	-0.05	-0.19
Reference	A	-0.22	0.07	-0.15	-0.29	-0.12	-0.33
Study	C	-0.14	0.14	0.00	-0.28	0.06	-0.35
Reference	C	-0.06	0.05	-0.01	-0.11	0.02	-0.14
Study	D	-0.14	0.11	-0.03	-0.25	0.02	-0.31
Reference	D	-0.15	0.08	-0.07	-0.23	-0.03	-0.27
Study	E	-0.20	0.05	-0.15	-0.25	-0.12	-0.28
Reference	E	-0.25	0.1	-0.15	-0.35	-0.10	-0.40
Study	F	-0.22	0.07	-0.14	-0.29	-0.11	-0.32
Reference	F	-0.19	0.11	-0.08	-0.30	-0.03	-0.36
Study	O	-0.14	0.09	-0.04	-0.23	0.00	-0.28
Reference	O	-0.17	0.07	-0.10	-0.24	-0.07	-0.28

Captions: SD = standard deviation; Comp. = component.

DISCUSSION

The purpose of this study was to characterize FFR with speech stimulus in a young adult population without hearing and language complaints attending higher education.

It is worth mentioning that the protocol proved to be easy and relatively fast (20 min on average) to apply. No participant reported discomfort during the assessment. Although the protocol used suggests that the examination be interrupted and that the electrodes be checked and repositioned if there is a number of artifacts larger than 20% of the stimulus (600/3000 sweeps), no case of presence of artifacts >20% was observed in the present study.

Variability of the FFR in the test and retest reveals good intra- and inter-subject reproducibility[8], which has been confirmed by several other studies[9,10,11]. Because this is a cross-sectional

study, no retest was performed, but inter-subject reproducibility was verified, that is, the assessed individuals presented similar responses.

The FFR with speech stimulus showed reliable measures, with each component concerning a characteristic of the stimulus, as exemplified in Figure 1. The resulting tracings of all participants of this study present configuration similar to the tracing corresponding to the speech stimulus /da/, as highlighted in the literature[3,12], which shows that this examination is truly capable of characterizing the auditory pathway response to the speech stimulus.

The age group chosen for this study, aged 21.1 years on average, is close to that of the research used as reference (24.21 years on average) for the female gender. This proximity between the age groups assessed is important because it is known that there is maturation of the FFR records throughout life[3,13].

The results found in this study were compared with the international reference values[6] for the female gender (Chart 1).

Analysis of the data on auditory evoked potentials is conducted by comparison with the reference study considering the positive and negative standard deviation (SD) values. It is customary to use between one and two standard deviation values for this comparison.

Comparison between the latency values showed that all peaks were within the range of +1 SD, except for peak E, which showed a latency value higher than that of the international study[6], and was in accordance with the reference when +2 SD was considered.

The slope value, according to national and international studies[8,14-16], is altered in individuals with learning and language disorders, which demonstrates the importance of carrying out this analysis.

In this study, a mean slope value of 0.23 was found and in comparison to the international reference[6], the slope value was within the expected, considering a standard deviation.

Comparison between the amplitude measures of the FFR components and the values of the international reference study[6] for females are shown in Chart 2, in which it can be verified that they were all within the +1 and -1 SD range, except for the amplitude of peak C, which was within the -1.5 SD.

The literature shows that, when analyzing the FFR, some researchers choose not to mark the C component because is not very representative, that is, relevant number of presence in the study sample[3]. However, in the present study, 100% presence of this component with latency and amplitude values similar to those of the international reference study adopted was observed[6]. Comparison between the other FFR components for the age group corresponding to the present study (21-30 years) showed that the mean latency measures are in line with those observed in the literature[3].

Several studies have associated FFR changes with changes in auditory, reading and phonological processing[5,16-22]. A recent study[23] highlighted the response properties of the FFR to speech and non-speech sounds for level dependence, adaptation, and phase-locking limits related to the stimulus.

This demonstrates the importance of having normality parameters, so that this can be a complementary examination used in the diagnosis, whose result can assist with guiding the intervention and can still be used in the evaluation of the results of this intervention.

Applicability of the FFR is promising, and new studies should address the standardization of this protocol also in the assessment of neonates and the elderly in the different types of hearing loss, as well as in learning impairments and language changes. In addition to the maturation inherent in the development of the auditory system, enriched (music, multilingualism, etc.) or private (low socioeconomic status, low education level) sound experiences could also produce slightly different development patterns, and deserve to be more comprehensively investigated[3].

The sample size used in the present study is smaller than those of the consulted studies; therefore, it is important to emphasize that a statistical sample calculation was performed, which defined a small sample size for this study due to the small variability between the component values of the individuals. Some limitations to the results of the present study in relation to the characteristics (age and gender) of the population assessed should be noted.

Data on the latency values of FFR components observed in an adult population without peripheral and/or central hearing disorders demonstrated inter-subject reproducibility, which shows that this is a reliable and easy-to-apply examination that can be used in clinical practice.

CONCLUSION

The electrophysiological measures obtained from the Frequency-following Response (FFR) using the speech stimulus /da/ in normal-hearing adults without hearing complaints presented slope, latency and amplitude values of all FFR components compatible with the normality standard described in the international literature.

REFERENCES

1. Kraus N, Anderson S, White-Schwoch T. The frequency-following response: a window into human communication. In: Kraus N, Anderson S, White-Schwoch T, Fay RR, Popper AN. The Frequency-Following Response: A Window into Human Communication. New York, NY: Springer-Nature, 2017. p. 1-15.
2. Skoe E, Kraus N. Auditory Brain Stem Response to Complex Sounds: A Tutorial. Ear Hear. 2010;31(3):302–24. https://doi.org/10.1097/AUD.0b013e3181cdb272. PMid:20084007.
3. Skoe E, Krizman J, Anderson S, Kraus N. Stability and plasticity of auditory brainstem function across the lifespan. Cereb Cortex. 2015;25(6):1415-26. https://doi.org/10.1093/cercor/bht311. PMid:24366906.
4. Filippini R, Schochat E. Potenciais evocados auditivos de tronco encefálico com estímulo de fala no transtorno do processamento auditivo. Braz J Otorhinolaringol. 2009;75(3):449-55. http://dx.doi.org/10.1590/S1808-86942009000300022.
5. Krishnamurti S, Forrester J, Rutledge C, Holmes GW. A case study of the changes in the speech-evoked auditory brainstem response associated with auditory training in children with auditory processing disorders. Int J Pediatr Otorhinolaryngol. 2013;77(4):594-604. https://doi.org/10.1016/j.ijporl.2012.12.032. PMid:23357780.
6. Krizman J, Skoe E, Kraus N. Sex differences in auditory subcortical function. Clin Neurophysiol. 2012;123(3):590-7. https://doi.org/10.1016/j.clinph.2011.07.037.

7. Wible B, Nicol T, Kraus N. Atypical brainstem representation of onset and formant structure of speech sounds in children with language-based learning problems. Biol Psychol. 2004;67(3):299-317. https://doi.org/10.1016/j.biopsycho.2004.02.002. PMid:15294388.

8. Russo N, Nicol T, Musacchia G, Kraus N. Brainstem responses to speech syllables. Clin Neurophysiol. 2004;115(9):2021-30. https://doi.org/10.1016/j.clinph.2004.04.003. PMid:15294204.

9. Song JH, Nicol T, Kraus N. Test–retest reliability of the speech-evoked auditory brainstem response. Clin Neurophysiol. 2011;122(2):346-55. https://doi.org/10.1016/j.clinph.2010.07.009. PMid:20719558.

10. Hornickel J, Knowles, Kraus N. Test-retest consistency of speech-evoked auditory brainstem responses in typically-developing children. Hear Res. 2012;284(1-2):52-8. https://doi.org/10.1016/j.heares.2011.12.005. PMid:22197852.

11. Anderson S, Parbery-Clark A, White-Schwoch T, Kraus N. Aging affects neural precision of speech encoding. J Neurosci. 2012;32(41):14156-64. https://doi.org/10.1523/JNEUROSCI.2176-12.2012. PMid:23055485.

12. Johnson KL, Nicol TG, Kraus N. Brain stem response to speech: a biological marker of auditory processing. Ear Hear. 2005;26(5):424-34. https://doi.org/10.1097/01.aud.0000179687.71662.6e. PMid:16230893.

13. Krizman J, Tierney A, Fitzroy AB, Skoe E, Amar J, Kraus N. Continued maturation of auditory brainstem function during adolescence: a longitudinal approach. Clin Neurophysiol. 2015;126(12):2348-55. https://doi.org/10.1016/j.clinph.2015.01.026. PMid:25801342.

14. Johnson KL, Nicol TG, Zecker SG, Kraus N. Auditory brainstem correlates of perceptual timing deficits. J Cogn Neurosci. 2007;19(3):376-85. https://doi.org/10.1162/jocn.2007.19.3.376. PMid:17335387.

15. Rocha CN, Filippini R, Moreira RR, Never IF, Schochat E. Potencial evocado auditivo de tronco encefálico com estímulo de fala. Pró-Fono. 2010;22(4):479-84. https://doi.org/10.1590/S0104-56872010000400020.

16. Sanfins MD, Borges LR, Ubiali T, Colella-Santos MF. Potencial auditivo de tronco encefálico com estímulo de fala (PEATE-fala) no diagnóstico diferencial de dificuldades escolares. Braz J. Otorhinolaringol. 2017;83(1):112-6. https://doi.org/10.1016/j.bjorl.2015.05.014.

17. Anderson S, Parbery-Clark A, White-Schwoch T, Kraus N. Auditory brainstem response to complex sounds predicts self-reported speech-in-noise performance. J Speech Lang Hear Res. 2013;56(1):31-43. https://doi.org/10.1044/1092-4388(2012/12-0043). PMid:22761320.

18. Kraus N, White-Schwoch T. Embracing the enigma of auditory processing disorder. Hear J. 2016;69(8):40-6. https://doi.org/10.1097/01.HJ.0000491121.04790.81.

19. Banai K, Hornickel J, Skoe E, Nicol T, Zecker S, Kraus N. Reading and subcortical auditory function. Cereb Cortex. 2009;19(11):2699-707. https://doi.org/10.1093/cercor/bhp024. PMid:19293398.

20. Abrams D, Kraus N. Auditory pathway representation of speech sound in humans. In: Katz J, Hood L, Burkard R, Medwetsky L. Handbook of Clinical Audiology. Baltimore: Lippincott. Willians & Wilkins; 2009. p. 611-26.

21. Rocha-Muniz CN, Befi-Lopes DM, Schochat E. Sensitivity, specificity and efficiency of speech-evoked ABR. Hear Res. 2014;317:15-22. https://doi.org/10.1016/j.heares.2014.09.004. PMid:25262622.

22. Rocha-Muniz CN, Filippini R, Neves-Lobo IF, Rabelo CM, Morais AA, Murphy CF, et al. Can speech-evoked Auditory Brainstem Response become a useful tool in clinical practice? CoDAS. 2016;28(1):77-80. https://doi.org/10.1590/2317-1782/20162014231. PMid:27074194.

23. Bidelman G, Powers L. Response properties of the human frequency-following response (FFR) to speech and non-speech sounds: level dependence, adaptation and phase-locking limits. Int J Audiol. 2018;15:1-8. https://doi.org/10.1080/14992027.2018.1470338. PMid:29764252.

Author contributions

ASD and SJO were responsible for study design, analysis and interpretation of data. They also were responsible for intellectually important writing of the manuscript and approval of the final version. SJO was responsible for data collection.