The Effect of Different Stimulation Rates on Brainstem Auditory-Evoked-Potential Responses

Kelly Cristina Lira de Andrade[1]   Ana Cláudia Figueiredo Frizzo[2]   Katielle Menezes de Oliveira[1]
Natália dos Santos Pinheiro[3]   Maria Cecilia dos Santos Marques[3]   Aline Tenório Lins Carnaúba[1]
Klinger Vagner Teixeira Costa[4]   Pedro de Lemos Menezes[1]

[1] Department of Audiology, Universidade Estadual de Ciências da Saúde de Alagoas (UNCISAL), Maceió, AL, Brazil
[2] Department of Audiology, Graduate program in speech therapy, Universidade Estadual Paulista "Júlio de Mesquita Filho" (UNESP), Marília, SP, Brazil
[3] Department of Audiology, Universidade Federal de Pernambuco (UFPE)
[4] Department of Medicine, Centro Universitário CESMAC, Maceió, AL, Brazil

Address for correspondence Kelly Cristina Lira de Andrade, PhD, Departmento de Audiologia, Universidade Estadual de Ciências da Saúde de Alagoas (UNCISAL), Rua Dr. Jorge de Lima 113, Trapiche da Barra, Maceió, Alagoas, 57010-300, Brazil (e-mail: kellyclandrade@gmail.com).

Abstract

Introduction   Auditory-evoked potentials are influenced by several factors, including polarity, filter, stimulus intensity and stimulation rate. The presentation of higher rates of stimuli per second enables the collection of a greater number of responses in a given period of time, promoting a shorter testing time; however, the collected recordings are subject to changes related to wave morphology.

Objectives   To compare the brainstem auditory-evoked-potential responses with click stimulus with the most commonly used stimulation rates in the clinical practice.

Methods   The present cross-sectional analytical study was performed with fifteen participants of both genders and normal hearing thresholds. The brainstem auditory-evoked potential was performed at four different stimulation rates (21.1, 26.7, and 27.7 stimuli/s, and a rate determined based on a mathematical calculation using the a measurement of the transmission frequency of the power grid at the time of the examination).

Results   We observed that the rate of 21.1 stimuli/s showed the highest amplitudes for waves I, III, and V when compared with the other rates. The rate of 26.7 stimuli/s, when compared with 27.7 stimuli/s, showed a higher amplitude for wave V. The latency if wave V was significantly lower with the rate of 21.1 stimuli/s than with 27.7 stimuli/s.

Conclusions   The stimulation rate interferes with wave latencies and amplitudes; its decrease from 27.7 to 21.1 stimuli/s decreases the latency of wave V and increases the amplitues and improves the morphology of waves I, III and V. In addition, we found evidence that suggests an improvement in the visualization of wave III by adjusting the stimulation rate based on a measurement of the local transmission frequency of the power grid.

Keywords
► hearing
► electrophysiology
► evoked potentials

Introduction

Auditory-evoked potentials (AEPs) are neuroelectric changes that occur in the peripheral and central nervous systems when they are exposed to certain sound stimulation. Such potentials can be classified according to latency as short-, medium- and long-latency AEPs.[1]

The brainstem auditory-evoked potential (BAEP) is a short-latency, objective and non-invasive electrophysiological test that records the electrical activity of the auditory system from the auditory nerve to the brainstem in a window of up to 10 milliseconds (ms).[2,3]

The BAEP responses are obtained through seven waves, and each wave comprises a structure of the auditory system; therefore, the distal portion of the auditory nerve is represented by wave I, the proximal portion is represented by wave II, wave III starts in the cochlear nuclei, waves IV and V can be assigned to the ipsi and contralateral lemniscus, and waves VI and VII can be characterized as the mesencephalic potential activities.[4]

To evoke BAEP responses, the most commonly-used stimuli are click and tone burst, with click as the most frequent as it is a transient and short-lived stimulus (100 μsec), which produces synchronous firing of auditory neurons, whose primary frequency is determined through a transducer-resonant frequency. Such a stimulus also has a broad spectrum, with maximum peak energy in regions ranging from 1,000 Hz to 4,000 Hz. The best relationship for pure-tone thresholds is between 2,000 Hz and 4,000 Hz.[5]

Some non-pathological variables should be considered in order to achieve a better understanding of the possibilities of BAEP responses. These include variables related to the individual, such as age, gender, drugs taken, body temperature, muscle artifacts, among others.[6–8]

Several stimulus-related variables influence AEPs, including polarity, filter, stimulus intensity and stimulation rate. The following is an example of a protocol used in the clinical practice to obtain BAEP recordings: click stimulus, condensation polarity, stimulus intensity of 80 dB HL, a rate of 27.7 stimuli/s and a bandpass filter of 100 Hz to 3,000 Hz.[9] The stimulation rates can be applied in different ways, and the rate of 27.7 stimuli/s is one of the most used in audiology services.[1,10] The presentation of higher rates of stimuli per second enables the collection of a greater number of responses in a given period of time, promoting a shorter testing time; however, the collected recordings are subject to changes related to wave morphology.[11] These changes are important and must be considered to standardize data and define protocols for the clinical practice.[12]

An important fact that must be considered when proposing studies on this topic is the transmission frequency of the power grid in Brazil. It runs at a 60 Hz sine wave; however, this value is not always found in the sockets. Thus, in an electrophysiological assessment, the use of a presentation rate adjusted based on a measurement of the local transmission frequency of the power grid can provide important information.

As modifications in this parameter may cause deformations in wave morphology, including the possibility of changes in latency and amplitude, the present study aimed to compare the BAEP responses with click stimulus at different rates in adults, including a presentation rate adjusted based on the measurement of the local frequency transmission of the electricity grid, and determine the best response possible with minimum wave deformation.

Methods

The present cross-sectional analytical study was performed at the Laboratory of Hearing and Technology after obtaining approval from the institutional Ethics in Research Committee Research under number 4.118.743. All participants signed the free and informed consent form.

The study included 15 individuals (30 ears), according to the central limit theorem, which states that the distribution of sample means approximates a normal distribution as the sample size gets larger.[13] The sample was aged between 19 and 35 years, with normal hearing thresholds (≤ 25 dB at frequencies from 250 Hz to 8000 Hz), presence of acoustic reflexes, and type-A tympanograms. The adopted exclusion criteria were: individuals with hearing impairment; any complaints relating to a central-auditory-processing disorder (CAPD); history of ear surgery; having had more than three ear infections in the current year; use of ototoxic medication; and presence of tinnitus, vertigo, dizziness or other cochleo-vestibular changes. A detailed anamnesis was applied to verify all these preestablished criteria.

After selecting the participants, the following procedures were performed:

1. Inspection of the external auditory canal to check its integrity and that of the tympanic membrane using a model mini-3000 (Heine Optotechnik GmbH & Co. KG, Gilching, Germany) otoscope;
2. Immittance audiometry, performed using the Interacoustics (Middelfart, Denmark) AT235 clinical tympanometer, to select participants with type-A tympanograms and acoustic reflexes;
3. Tonal and vocal audiometry, using the Interacoustics model Ad 629 audiometer and supra-aural model DD45 headphones, in an acoustic booth by Vibrasom (São Bernardo do Campo, SP, Brazil), according to S3.1 recommendations of the American National Standards Institute (ANSI).[14] The objective was to identify normal auditory tonal and vocal thresholds. Tonal audiometry is a psycho-acoustic method to research hearing thresholds, and it was performed using the descending technique, with 10-dB intervals, and the ascending technique with 5-dB intervals, to confirm the responses. Frequencies with octave ratios between 250 Hz and 8,000 Hz were evaluated, including the interoctave frequencies of 3,000 Hz and 6,000 Hz;
4. The BAEP was performed using the Bio-logic Navigator PRO AEP equipment(Natus Medical, Inc., Pleasanton, CA, United States). The participant was instructed to lie down in an armchair, with the body and muscles relaxed to

reduce the artifacts from muscle action. The testing site remained poorly lit, silent, and with few visual distractions. The skin was cleaned with abrasive paste and then the electrodes were fixed with microporous tape, using an electrolytic paste to improve electrical conductivity. Surface electrodes were placed at predetermined positions: the inverter electrode at M1 and M2 (related to the right ear and left ear respectively, fixed on the mastoids); the non-inverter electrode at Fz; and the reference (ground) at the Fpz position, according to the 10–20 International Electrode System (IES). The impedance between the electrodes was maintained at a level below 5 kΩ. The protocol used to capture the recordings was the click stimulus, with a duration of 0.1 µV, rarefaction polarity, presented monaurally at 80 dB HL, at different stimulation speeds per second, employing a total of 2,000 stimuli, with 150 Hz high-pass filters and 3,000 Hz low-pass filters, 10-ms window, and artifact rejection with peaks over 23.73 µV or valleys below -23.73 µV.

The stimuli were randomly presented at rates of 21.1, 26.7, and 27.7 stimuli/s. In addition, a fourth stimulation rate was presented, based on a mathematical calculation performed on the Excel (Microsoft Corp., Redmond, WA, US) software, version 14.4.2 for Mac OS. The transmission frequency of the power grid at the time of the examination was measured using an oscilloscope.

The mathematical calculation is as follows:

$$\%SRE = \left[Sen\left(\frac{TFPG}{ASR}\right).2\eth\right].100,$$

in which, % SRE is the percentage of stimulation rate efficacy in relation to the transmission frequency of the power grid, TFPG is the transmission frequency of the power grid, and ASR is the adjusted stimulation rate.

The TFPG was obtained with an oscilloscope. Thus, after recording the electrical voltage (mV) in relation to time (ms), a Fast Fourier Transform was applied, by the oscilloscope itself, to obtain the frequency spectrum. Finally, after obtaining the TFPG, the data were inserted into the formula programmed in the spreadsheet, to obtain the ASR. The spreadsheet automatically searched for the ASR close to 27.7 stimuli/s with the highest %SRE. This was the fourth rate used in the investigation, and it varied according to the TFPG at the time of the examination.

The power grid in Brazil runs at a 60 Hz sine wave; however, this value is not always exactly the one that reaches the sockets. In addition, it is not recommended that the AEP stimulation rate be applied at multiples or submultiples of the TFPG, for a mechanism called "phase-locked" (phase synchronism) may occur. In this condition, the acquisitions of the biopotentials would always occur in the same phase of the power grid, which would cause a distortion in the wave's amplitude, especially if this phase synchronism tends to the extremities of the wave's peak or valley.

Thus, the adjusted stimulation rate, in other words, is the frequency closest to 27.7 stimuli/s, that has the lowest resonance with the power grid, which, in theory, would

enable the obtainment of signals with less interference from that grid.

Two recordings were obtained for each stimulation rate and for each of the 30 ears, thus verifying the tracing reproduction and confirming the existence of responses. The BAEP was recorded by a trained examiner, and wave marking was performed by two examiners experienced in electrophysiology. When the tracing was difficult to analyze and there was no agreement regarding the marking, discussions were held among all professionals involved in the study, and a consensus was reached. The marking and identification of each peak was performed manually, thus evaluating its morphological characteristics and relevant temporal aspects. The absolute latencies and amplitudes of waves I, III, V were analyzed.

Statistical Analysis

The statistical analysis was performed using the Statistical Package for the Social Sciences (IBM SPSS Statistics, IBM Corp., Armonk, NY, United States), version 23.0 for Macbook. For the description of the data, tables and graphics with means and standard deviations (SDs) were used. Initially, an evaluation of the sample was performed to observe its adherence to the normal distribution using the Shapiro-Wilk test.

The analysis of latencies and amplitudes according to the stimulation rates was performed using the Friedman test, and the Wilcoxon signed-rank test was used to analyze the differences between stimulation rates by pairs,. The evaluation of artifacts according ot the stimulation rates was performed using the Friedman test. The differences were considered statistically significant with values of $p < 0.05$.

Results

The sample consisted of 15 participants of both genders, 6 (40%) male and 9 (60%) female subjects. The average age of the men was 20.5 years (SD: 1.3 years), and that of the women was 23.4 years (SD: 4.6 years). The age of the total sample ranged from 19 to 35 years.

The ASRs from the mathematical calculation and those obtained with the aid of the oscilloscope at the time of the examination varied between two values: 26.6 stimuli/s for 3 participants, and 27.0 stimuli/s for 12 participants.

►**Table 1** presents the data obtained from the descriptive analysis (mean, SD, and confidence interval) of the latencies and amplitudes of waves I, III, and V in the studied stimulation rates.

The general analysis of latencies and amplitudes according to the stimulation rates, performed using the Friedman test, showed a statistically significant difference ($p < 0.01$).

For the analysis of the latencies by pairs of used stimulation rates, with the Wilcoxon test, there was a statistically significant difference only in the latency of wave V between the rates of 21.1 and 27.7 stimuli/s (mean: 5.38 ms and 5.45 ms respectively; $p = 0.048$) and between the rates of 21.1 stimuli/s and the ASR (mean: 5.38 ms and 5.46 ms respectively; $p = 0.049$).

Table 1 Descriptive analysis of the latencies (ms) and amplitudes (µV) of waves I, III and V in the right and left ears of the 15 participants (30 ears) according to the stimulation rate

Stimulation rate (stimuli/s)	Mean ± standard deviation			95% confidence interval		
				(lower limit–upper limit)		
	Wave I	Wave III	Wave V	Wave I	Wave III	Wave V
Latency (ms)						
21.1	1.39 ± 0.25	3.51 ± 0.30	5.44 ± 0.24	1.29–1.48	3.40–3.62	5.35–5.53
26.7	1.42 ± 0.28	3.52 ± 0.28	5.43 ± 0.33	1.32–1.53	3.42–3.43	5.31–5.56
27.7	1.38 ± 0.29	3.47 ± 0.32	5.50 ± 0.26	1.27–1.50	3.35–3.59	5.41–5.60
ASR	1.46 ± 0.24	3.50 ± 0.30	5.47 ± 0.25	1.37–1.56	3.39–3.61	5.38–5.57
Amplitude (µV)						
21.1	0.36 ± 0.18	0.41 ± 0.19	0.56 ± 0.16	0.29–0.43	0.34–0.48	0.50–0.62
26.7	-0.02 ± 0.21	0.13 ± 0.26	0.46 ± 0.22	-0.10–0.05	0.03–0.22	0.38–0.55
27.7	-0.08 ± 0.24	0.09 ± 0.21	0.36 ± 0.18	-0.17–0.01	0.01–0.17	0.29–0.43
Adjusted stimulation rate	-0.91 ± 4.93	0.21 ± 0.26	0.44 ± 0.17	-2.75–0.93	0.10–0.31	0.37–0.50

►**Table 2** shows the amplitude results with a statistically significant difference by pairs of used stimulation rates. We observed that the rate of 21.1 stimuli/s had the highest amplitudes whenever compared with other rates.

►**Fig. 1** shows the grand average of the BAEP wave recordings obtained according to the stimulation rate used.

►**Table 3** presents the data obtained from the descriptive analysis (mean, SD, and confidence interval) of the artifacts according to the stimulation rate used.

The general evaluation of the artifacts, using the Friedman test, did not result in a statistically significant difference ($p > 0.05$).

Discussion

The rate of presentation of stimuli is a parameter related to the speed the acoustic stimulus travels through the auditory pathways to the brainstem, as it corresponds to the refractory period of the neural structure. Higher rates can be used to sensitize the BAEP recording, to assess neural synchronism, and to identify neurological disorders.[11]

Due to the possibility of using different rates of presentation of stimuli, it is important that all possible findings and their implications for the clinical practice are clarified and discussed, as changes in the BAEP wave morphology can lead

Table 2 Results with statistically significant differences in amplitude according to the pairs of stimulation rates evaluated

Pairs of stimulation rates (stimuli/s)	Wave	Mean rate 1 (µV)	Mean rate 2 (µV)	*p*-value
21.1–26.7	I	0.40	0.09	0.000
	III	0.48	0.25	0.000
	V	0.58	0.49	0.009
21.1–27.7	I	0.40	0.05	0.000
	III	0.48	0.22	0.000
	V	0.55	0.39	0.000
21.1–adjusted stimulation rate				
	I	0.40	0.09	0.000
	III	0.48	0.32	0.004
	V	0.55	0.46	0.001
26.7–adjusted stimulation rate	III	0.25	0.32	0.043
27.7– adjusted stimulation rate	III	0.22	0.32	0.013
	V	0.39	0.46	0.022
26.7–27.7	V	0.49	0.39	0.013

Note: The Wilcoxon signed-rank test was used to analyze the differences between stimulation rates by pairs.
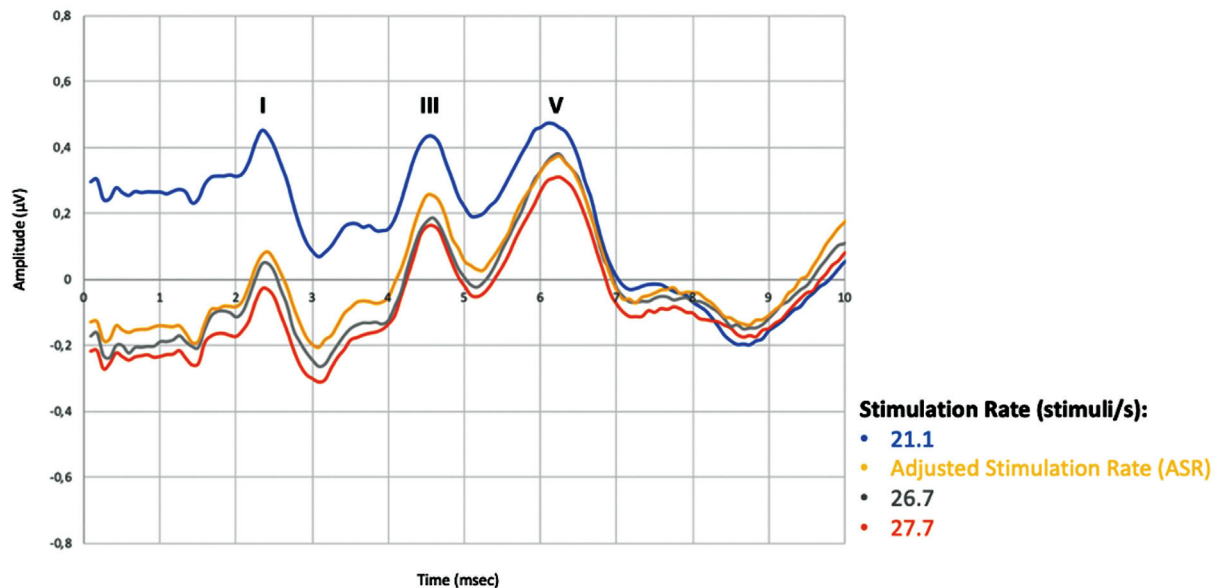
Fig. 1 Grand average of the BAEP waves according to the stimulation rate used in the study (21.1, 26.7, 27.7 stimuli/s, and the ASR).

Table 3 Descriptive analysis of the artifacts according to the stimulation rate

Stimulation rate (stimuli/s)	Mean	Standard deviation	95% confidence interval	
			Lower	Upper
21.1	150.13	129.15	116.77	183.50
26.7	170.77	139.33	134.77	206.76
27.7	161.48	177.29	115.68	207.28
Adjusted stimulation rate	172.47	174.33	127.43	217.50

to mistakes in markings and, consequently, mistakes in assessments and incorrect diagnoses.

The present study evaluated four different click stimulus presentation rates in the BAEP, which were determined based on the following criteria: 1) frequent use in the clinical practice (27.7 stimuli/s);[11] 2) proximity to the rate used in the clinical practice, but with less resonance with the power grid, corresponding to 60 Hz (26.7 stimuli/s);[15] 3) mentions in the literature as usual (21.1 stimuli/s);[16] amd 4) ASR according to the power grid at the time of the examination. This adjustment would provide better knowledge about latency and amplitude recordings, because, theoretically, it would control the artifact inputs from the power grid, which could contribute to better wave morphology.

Among the used rates, there was a better morphology of waves I, III, and V with the rate of 21.1 stimuli/s (►**Fig. 1**), which comprises the slowest investigated stimulation rate. The use of slower rates is indicated when there is a need to identify the components and amplitude of the first BAEP waves.[17]

In 1991, the Committee on Infant Hearing American Speech-Language-Hearing Association suggested the use of click stimulus with a 21.1 stimuli/s repetition rate in the rarefaction and condensed polarities, with the justification that, at this rate, wave morphology showed better visual-izations, which would assist with the verification of the presence of cochlear microphonism, to identify auditory neuropathy spectrum disorders.[18]

In a study[19] with 59 patients diagnosed with severe or profound hearing loss, the authors modified the characteristics of the click stimulus to sensitize the BAEP performance. According to the authors, changes in the characteristics of the acoustic stimulus in the BAEP with the use of faster stimulation rates may cause less reproduction and clarity of the waves, in contrast to slower stimulation rates, which can increase amplitude and significantly improve the wave pattern. Thus, the study[19] suggested the use of the slowest recording technique in all patients with and without hearing loss. Likewise, the present study showed, when comparing the rates of 27.7 and 21.1 stimuli/s, statistically significant differences in the values referring to the amplitudes of waves I, III, and V, with better recordings for the rate of 21.1 stimuli/s.

Another important issue refers to the differences that can be found in the BAEP recording depending on the assessed population. The absolute latency time and wave amplitude can be influenced, for instance, by factors related to age, with increased latency and decreased amplitude with increasing age.[6] For young children, due to the incomplete myelinization

of neuron axons, prolonged neural transmission and increased latency of responses are found.[20]

A study[21] evaluated the BAEP of children with suspected CAPD and showed a significantly-prolonged latency of wave V at faster stimulation rates when compared with age-matched typically developing children. The BAEPs were recorded at slow (13.3 stimuli/s) and faster (57.7 stimuli/s) rates.

The choice of rate of presentation of stimuli can be determined by age.[11] In infants, for example, the rate of 27.7 stimuli/s can result in a quicker test, as the behavioral pattern of infants or younger children does not enable the use of slower rates, and this factor increases the examination time, making the procedure more difficult. However, in older children (or younger ones, but using sedation) and adults who respond to commands and, in turn, can contribute by remaining at rest during the test, the stimulation rate could be slower.

In addition, another point of discussion is quite relevant when evaluating the clinical applicability of the technique of presenting stimuli based on the concept of refractory period. It is known that a nerve fiber needs a critical amount of time to recover from a previous stimulus and, during this period, it cannot trigger another recording response. Therefore, when nerve fibers are changed, they require a longer refractory period. Therefore, the stimulus presented at a high repetition rate causes a shorter recovery period in the nerve fibers, which can trigger poor synchrony, with changed waves in the BAEP.[22]

All of these aspects are important and should be considered to standardize data and define protocols in the clinical practice. The increase in this specific parameter can cause changes in wave latency and amplitude, with a reduction in amplitude and a wave prolongation, which alter the BAEP wave latencies. For individuals with normal hearing, when the stimulus presentation rate is increased from 10 to 100 stimuli/s, the lagtency of wave V increases ~ 0.5 ms, and the amplitude decreases.[12] Similar results were found in the present study, in which an increase in the latencies of wave V at higher rates of stimulation (21.1 versus 27.7 stimuli/s and 21.1 versus the ASR) was observed, and higher amplitudes were always observed at lower rates (21.1 stimuli/s).

A study[23] on the effect of the click rate on the latency of BAEPs was performed with six individuals with normal hearing at rates of 10, 30, 50 and 100 stimuli/s, and at intensities of 30, 40, 50 and 60 dBSPL. The authors[23] found differences in the absolute latency of wave five of around 0.5 ms, when comparing the repetition rates of 10 and 100 stimuli/s. In addition, the four tested intensities triggered the same change in the latency of wave V, even with the variation in stimulation rates. The authors also observed a reduction in the amplitude of wave V with an increase in the stimulation rate.

In a study with adults with normal hearing, the author[24] observed that changes in stimulus speed from 10 to 80 stimuli/s resulted in an increase of 0.14, 0.23 and 0.39 ms for waves I, III, and V respectively. In neonates, the same increase in rate triggers a latency increase of 0.8 ms for

wave V. In relation to amplitude, this increase promotes a 50% reduction in waves I and III, and only 10% in wave V. The amplitude of wave I decreases only 10% with stimulation rates of ~ 20 stimuli/s. In addition, the author[24] noted that no significant changes are observed in amplitude with an increase in the rate from 11 to 61 stimuli/s in infants. Finally, repetition rates of around 50 stimuli/s are more efficient to visualize wave V; however, to observe wave I, rates between 20 and 40 stimuli/s are more appropriate.

In the present study, when comparing the rate of 27.7 stimuli/s with the ASRs, significant differences were found for the amplitudes of waves III and V, attesting that the ASRs are responsible for the amplitudes with better visualization. It should be noted that the ASRs were of 26.6 stimuli/s for 3 participants and 27.0 stimuli/s for 12 participants.

The comparison of the rate of 26.7 stimuli/s with the ASRs, in turn, only showed a difference for the amplitude of wave III, with higher amplitudes for the ASRs. This important finding strengthens the thesis that automated adjustments in stimulation rates that take into account the local TFPG can improve the acquisition of the tested signals.

It is a consensus in the literature that the increase in the speed of acoustic stimuli affects the BAEP wave behaviors differently. Waves I and III, for example, are more influenced than wave V, which remains more robust at high stimulation rates.[11]

To delve deeper into the morphological differences presented in ►**Fig. 1**, explanations in the field of Biophysics should be made. It is impossible to have negative neuron responses as the neuron potential is linked to positive ions. Therefore, the positive/negative nomenclature is based only on the habit of using this term, as the electrodes can only generate positive responses.[25]

According to the findings of the present study, the responses generated with the rate of 21.1 stimuli/s did not show negative amplitudes; however, the faster rates, such as 27.7 stimuli/s, showed negative amplitude peaks (►**Table 1**). Apparently, according to the presented results, the increase in speed decreases the amplitude, and lower amplitudes are more susceptible to signal changes due to fluctuations in the power grid.

The amplitude analysis, following the adjustment criteria according to the power grid, showed only positive peaks; however, all of them were below the rate of 21.1 stimuli/s. This data indicates that the rate of 21.1 stimuli/s is less influenced by the power grid, a fact evidenced in ►**Fig. 1** of the present study, which presents the rate of 21.1 stimuli/s with a prominent morphology and impeccable visualization when compared with the other evaluated rates.

Another analysis is necessary when considering the use of different rates of presentation of stimuli rates due to the possibility of reducing the test time. Currently, given the short time available to carry out all activities, adjusting a certain protocol parameter to reduce testing time is often more valued than the implications of this choice to the evaluation findings.

In addition, the time to perform 2,000 recordings is of 1.60 minute, 1.24 minute and 1.20 minute respectively for

the rates of 21.1, 26.7, and 27.7 stimuli/s. A gain of ∼ 40 seconds per test alone would not justify the use of a higher rate. It would also be necessary to maintain the wave's morphology.

So, this increase in the stimulation rate can cause changes in wave morphology, especially regarding amplitude, which may result in difficulties in marking the peaks and interfering with the reliability of the diagnosis. The decrease in amplitude could make it difficult to visualize wave V in the threshold search, for example.

Regarding the artifacts presented according to the stimulation rate, we found no statistically significant difference, a fact possibly justified by two factors: 1) the high variability, with SDs that approximate or exceed the mean values. Such variability does not enable one to safely define of differences between groups; 2) the low sensitivity of artifact rejection, which is configured to eliminate records with peaks above 23.73 μV or valleys below -23.73 μV. Thus, small improvements or worsening in noise levels may have gone unnoticed by this measure. It is likely that a detailed noise assessment, with an analysis of the frequency domain, and also with the possibility of individual analysis of the records, will reveal important findings to be considered in the clinical practice.

Despite the limited number of participants, the present study yielded important and reliable findings regarding the discussion on the use of different rates of presentation of click stimuli in the BAEP. It is noteworthy that the BAEP was performed at 80 dB HL, focusing on the peaks of waves I, III, and V, analysis condition restricted to the assessment of the auditory pathway integrity. However, further studies to delve deeper into the topic are essential, with the possibility of assessments with different age groups, populations with hearing loss, as well as a study aimed at researching the electrophysiological threshold from the change in this parameter.

Thus, the importance of the examiner's knowledge about the choice of parameters is reinforced, in particular, the rate of presentation of stimuli rate for each protocol defined during the performance of electrophysiological assessments.

Conclusion

The present study demonstrated that the stimulation rate interferes with wave latencies and amplitudes. Its decrease from 27.7 to 21.1 stimuli/s, in the BAEP, decreases the latency of wave V and increases the amplitudes of waves I, III, and V, improving wave morphology. Finally, we found evidence suggesting an improvement in the visualization of wave III by adjusting the stimulation rate based on a measurement of the local TFPG.

Author Contributions
1. Kelly Cristina Lira de Andrade: conception, study design, data acquisition, data analysis and discussion, and writing of the article.
2. Ana Cláudia Figueiredo Frizzo: conception, study design, data acquisition, data analysis and discussion, and writing of the article.
3. Katielle Menezes de Oliveira: data analysis and conception of the article.
4. Natália dos Santos Pinheiro: data acquisition, data analysis and discussion, and writing of the article.
5. Maria Cecilia dos Santos Marques: data acquisition, data analysis and discussion, and writing of the article.
6. Aline Tenório Lins Carnaúba: data acquisition, data analysis and discussion, and writing of the article.
7. Klinger Vagner Teixeira Costa: data acquisition, data analysis and discussion, and writing of the article.
8. Pedro de Lemos Menezes: conception, study design, data acquisition, data analysis and discussion, and writing of the article.

Conflict of Interests
The authors have no conflict of interests to declare.

References

1 Andrade KCL, Pinheiro NS, Carnaúba AT, Menezes PL. Potencial Evocado Auditivo de Tronco Encefálico: conceitos e aplicações clínicas. In: Menezes PL, et al. (org.). Tratado de Eletrofisiologia para Audiologia. 1. Ed. São Paulo: Book Toy; 2018:73–83
2 Hall JW. Application of ABR in Objective Assessment of Infant Hearing. Audiology Online. 2013:p.1–17
3 Bakhos D, Marx M, Villeneuve A, Lescanne E, Kim S, Robier A. Electrophysiological exploration of hearing. Eur Ann Otorhinolaryngol Head Neck Dis 2017;134(05):325–331
4 Souza LCA, Piza MRT, Alvarenga KF, et al. Eletrofisiologia da audição e Emissões Otoacústicas princípios e aplicações clínicas. Ribeirão Preto: BookToy; 2016, p. 49–87.
5 Rosa BCS, Cesar CP, Cabral A, Santos M, Santos R. Potencial Evocado Auditivo de Tronco Encefálico com estímulos clique e Ichirp. Distúrb Comun 2018;30(01):52–59
6 Esteves MCBN, Aringa AHBD, Arruda GV, Aringa ARD, Nardi JC. Estudo das latências das ondas dos potenciais auditivos de tronco encefálico em indivíduos normo-ouvintes. J Bras Otorrinolaringologia. 2009;75(03):420–425
7 Stockard JJ, Stockard JE, Sharbrough FW. Nonpathologic Factors Influencing Brainstem Auditory Evoked Potentials. Am J EEG Technol 1978;18(04):177–209
8 Abulebda K, Patel VJ, Ahmed SS, Tori AJ, Lutfi R, Abu-Sultaneh S. Comparison between chloral hydrate and propofol-ketamine as sedation regimens for pediatric auditory brainstem response testing. Rev Bras Otorrinolaringol (Engl Ed) 2019;85(01): 32–36
9 Cargnelutti M. Potencial Evocado Auditivo de Tronco Encefálico com estímulo clique e ichirp em neonatos. Rio Grande do Sul: Universidade Federal de Santa Maria; 2016:80 p
10 Beatini JR, Proudfoot GA, Gall MD. Effects of presentation rate and onset time on auditory brainstem responses in Northern saw-whet owls (Aegolius acadicus). J Acoust Soc Am 2019;145(04): 2062–2071
11 Møller AR. Intraoperative neurophysiologic monitoring. Am J Otol 1995;16(01):115–117
12 Hood LJ. Clinical applications of the Auditory Brainstem Response: introduction and overview. San Diego; London: Singular Publishing; 1998
13 Bussab WO, Morettin PA. Estatística Básica. 5ª edição. São Paulo: Saraiva,; 2002. p. 272.
14 American National Standard Institute. Specifications for audiometers. ANSI S3.6. EUA. 1991
15 Arruda EF. Análise de distúrbios relacionados com a qualidade da energia elétrica utilizando a transformada Walevet. São Carlos: Universidade de São Paulo; 2003. 136 p.

16 Bento DV. Influência da Taxa de Repetição do Estímulo Clique na Latência e Amplitude do Potencial Evocado Auditivo de Tronco Encefálico. São Paulo: Pontifícia Universidade Católica de São Paulo; 2012. 106 p.

17 Cubero-Rego L, Ricardo-Garcell J, Corsi-Cabrera M, et al. Improving the efficiency of Auditory Brainstem Responses in newborns, using a 60clicks/s stimulation rate. J Clin Neurosci 2017;45: 299–304

18 Committee on Infant Hearing American Speech-Language-Hearing Association. Guidelines for the audiologic assessment of children from birth through 36 months of age. ASHA Suppl 1991;33(05):37–43

19 Fávero ML, Silva FLC, Junior AT, Nicastro FS, Gudmond MC, Spinelli M. Mudanças nos parâmetros do clique durante a captação do BERA. Rev Bras Otorrinolaringol 2007;73(01):7–11

20 Griz SMS, Menezes PL. Potencial evocado auditivo de tronco encefálico: parâmetros técnicos. In: Menezes PL (org.). Tratado de Eletrofisiologia para Audiologia. 1. ed. São Paulo: Book Toy; 2018:p. 65–73

21 Ankmnal-Veeranna S, Allan C, Allen P. Auditory Brainstem Responses in Children with Auditory Processing Disorder. J Am Acad Audiol 2019;30(10):904–917

22 Burkard RF, Don M. The auditory brainstem response. In: Burkard RF, Don M, Eggermont JJ, eds. Auditory evoked potentials basic principles and clinical application. Philadelphia: Lippincott Williams & Wilkins; 2007:229–250

23 Don M, Allen AR, Starr A. Effect of click rate on the latency of auditory brain stem responses in humans. Ann. Washington: University Department of Otolaryngology.; 1997. p. 186–195.

24 Stapells D. Auditory brainstem response assessment of infants and children. Semin Hear 1989;10(03):229–251

25 Azambuja AA, Oliveira JR, Pereira LLM, Giaretta DS. Potencial de ação. In:Oliveira JR, (org.). Biofísica: para ciências biomédicas. 4. ed. Porto Alegre: PUCRS; 2014:p. 57–69