

Binaural interaction component of the long-latency auditory evoked potential with speech stimulus: descriptive values in typical young adults

Componente de interação binaural do potencial evocado auditivo de longa latência com estímulo de fala: valores descritivos em adultos jovens típicos

Componente de interacción binaural del potencial evocado auditivo de larga latencia con estímulo de habla: valores descriptivos en adultos jóvenes típicos

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Abstract

Objective: To describe the values of the Binaural Interaction Component of the Long-Latency Auditory Evoked Potential (verbal) in typical young adults. **Method:** It is an observational descriptive study. Ten adults with normal hearing thresholds, no auditory complaints, and normal central auditory processing and cognition were evaluated. All participants underwent a basic audiological evaluation, self-perception assessment of auditory abilities, central auditory processing evaluation, neuropsychological assessment, and long-latency auditory evoked potential measurement. **Results:** Absolute latency, amplitude, and duration values for the binaural interaction component were described. **Conclusion:** The present study provided normal latency, amplitude, and duration measures for the binaural interaction component.

Keywords: Electrophysiology; Hearing; Adults; Audiology.

Resumo

Objetivo: Descrever os valores do Componente de Interação Binaural do Potencial Evocado Auditivo de Longa Latência (verbal) em adultos jovens típicos. **Método:** Trata-se de um estudo observacional descritivo. Dez adultos com limiares auditivos normais, sem queixas auditivas e com processamento auditivo central e cognição normais, foram avaliados. Todos os participantes passaram por uma avaliação audiológica básica, avaliação da autopercepção das habilidades auditivas, avaliação do processamento auditivo central, avaliação neuropsicológica e medição do potencial evocado auditivo de longa latência. **Resultados:** Foram descritos valores de latência absoluta, amplitude e duração para o componente de interação binaural. **Conclusão:** O presente estudo forneceu medidas descritivas de latência, amplitude e duração para o componente de interação binaural do potencial evocado auditivo de longa latência.

Palavras-chave: Eletrofisiologia; Audição; Adultos; Audiologia.

Resumen

Objetivo: Describir los valores del Componente de Interacción Binaural del Potencial Evocado Auditivo de Larga Latencia (verbal) en adultos jóvenes típicos. **Método:** Se trata de un estudio observacional descriptivo. Se evaluaron a diez adultos con umbrales auditivos normales, sin quejas auditivas, y con procesamiento auditivo central y cognición normales. Todos los participantes se sometieron a una evaluación audiológica básica, a una autoevaluación de sus habilidades auditivas, a una evaluación del procesamiento auditivo central, a una evaluación neuropsicológica y a la medición del potencial evocado auditivo de larga latencia. **Resultados:** Se describieron los valores de latencia absoluta, amplitud y duración para el componente de interacción binaural. **Conclusión:** El presente estudio proporcionó medidas normales de latencia, amplitud y duración para el componente de interacción binaural.

Palabras clave: Electrofisiología; Audición; Adultos; Audiología.

Introduction

Binaural integration refers to the listener's ability to process different information presented simultaneously to both ears, while binaural interaction (BI) is a complex phenomenon that occurs in the human auditory system when the left and right ears process sound information together. The *British Society of Audiology* (BSA)¹ considers BI to be one of the main mechanisms for Central Auditory Processing (CAP), since it makes it possible to synthesize dichotic acoustic signals that are separated by spectral differences in time, frequency or intensity. This ability enables better localization and lateralization of the sound source, as well as adequate speech recognition in noise or with competing and/or degraded acoustic signals^{2,3}.

Given the importance of BI, it is recommended that at least one test be included in the battery of behavioral assessments, such as the *Masking Level Difference* (MLD) or the Binaural Fusion Test (BFT), to verify the performance of this ability. However, it is suggested that these be associated with objective tests, so that the functional capacity can be related to the neurobiological capacity of the auditory pathway^{1,4}.

Due to the need to correlate neurophysiological measures with behavioral ones, the Binaural Interaction Component (BIC) can be used as a complementary assessment to measure CAP, since it refers to an objective response of neurons tuned to synthesize binaural information⁵. This use is justified due to the clinical applicability of the BIC in analyzing cortical and cognitive processing in an objective way, since the authors have shown that this analysis can be considered an attractive neural correlation of binaural behavior performance^{6,7}.

BIC can therefore provide evidence of binaurally, since the electrical response evoked by a bilateral stimulus, despite having lower morphology and amplitude in its recording, generates more specific responses in relation to binaural structures than the sum of the responses evoked by a monaural stimulus. Thus, the use of this analysis makes the measurement of BI more reliable. A study by McPherson and Starr (1993) concluded that the BIC extends for several milliseconds in the brainstem to the most cortical region and is represented by a reduction in the amplitude of the binaural Auditory Evoked Potential (AEP) in relation to the sum of the monaural responses⁵. In addition, they observed

that binaural processing in the auditory pathway by means of AEP reflected greater activity in the thalamus and cortical portions of the auditory pathways, demonstrating the importance of these structures in binaural performance and its measurement.

Authors have demonstrated the correlation between the Long Latency Auditory Evoked Potential (LLAEP) and the CAP, due to the structures responsible for eliciting the potential, specifically the thalamocortical regions, which are extremely important for binaural processing, justified by their relationship with decoding, recognition, discrimination, attention and auditory memory⁸.

This research is therefore justified by the need to verify cortical and cognitive BI using the LLAEP-verbal in young adults. By understanding their typical behavior, it will be possible to use it as a complementary tool to behavioral assessment^{7,8}. The aim of this study is therefore to describe the BIC values of the LLAEP-verbal in typical young adults.

Materials and methods

Study design

This is a descriptive observational study, approved by the Research Ethics Committee under number 56038322.1.0000.5346. The data was collected at the research clinic of the institution of origin, from March 2023 to March 2024. All participants were instructed and signed an informed consent form (ICF). In addition, individuals who had complaints or alterations in the evaluations were given guidance on the findings and directed, if they were interested, to rehabilitation at the institution of origin.

Sample composition

The study sample was made up of typical young adults of both sexes who had no complaints and were normal in the assessments carried out regarding hearing, auditory processing and cognitive aspects. The eligibility criteria were as follows:

- Young adults aged between 18 and 35;
- Both sexes;
- Brazilian Portuguese speakers;
- Hearing thresholds within the normal range in the frequencies conventionally assessed, i.e. up to 19 dBHL in the frequencies from 250 to 8000 Hz;
- Normality of the tympano-ossicular system;

- Stapedial acoustic reflexes present at normal levels;
- Self-perception of normality in CAP skills;
- Normality in central auditory processing tests;
- Normal neuropsychological assessment, i.e. cognitive skills of attention and memory;
- Integrity of the auditory pathway at brainstem level, measured by Brainstem Auditory Evoked Potential - neurodiagnosis;
- Presence of all the components of the Long Latency Auditory Evoked Potential.

Subjects were excluded if they had,:

- Apparent or diagnosed cognitive, psychiatric and/or neurological alterations;
- History of head or brain trauma;
- Perception of chronic tinnitus;
- Dizziness;
- Continuous exposure to noise;
- Musicians;
- Bilingual.

Individuals who had been exposed to musical practice and were bilingual were excluded because they had better sound information processing^{9,10}.

Participants

A total of 41 individuals were seen during the collection period. For the study, 10 individuals were considered (eight women and two men), aged between 18 and 23 years (mean age = 20.20 years, standard deviation = 1.87) and all with a high level of schooling (mean schooling = 15.10 years, standard deviation = 1.59), who met the eligibility criteria.

For a better understanding of the methodology, the procedures were divided into sample composition procedures (audiological, central auditory processing, cognitive and electrophysiological hearing assessments) and research procedures (binaural interaction component). It should be noted that the assessments were carried out over two days, the first of which was focused on behavioral procedures (initial assessment, audiological assessment, central auditory processing and neuropsychological assessment) and the second on electrophysiological assessments (Brainstem Auditory Evoked Potential and Long Latency Auditory Evoked Potential).

Procedures for sample composition

Audiological assessment

- **Semi-structured anamnesis:** carried out with the aim of collecting information on the participants' identification data, previous illnesses, as well as questions related to hearing and the eligibility criteria. It consisted of questions related to hearing, auditory processing and cognitive complaints, lifestyle habits and previous and current health history.
- **Visual inspection of the external acoustic meatus:** a Mikatos model TK otoscope was used to check for any alterations that would prevent the procedures from being carried out. If there were any alterations, the individual was referred for medical attention.
- **Pure tone audiometry (PTA):** carried out in a soundproof booth, using an *Interacoustics* AD229 audiometer and TDH 39 headphones. Airway hearing thresholds were investigated at the frequencies conventionally assessed (250 to 8,000 Hz), and hearing thresholds were considered to be within normal limits when up to 19 dBHL were present¹¹. It should be noted that the thresholds were analyzed by frequency in isolation, since any alteration, even the slightest, can lead to impaired decoding.
- **Logoaudiometry:** carried out on the same equipment as the ATL, consisting of two stages: The first was the Speech Recognition Threshold test, adding 30 dBHL above the tritone mean, using the descending-ascending technique, considering the individual's threshold when they correctly repeated 50% of the four presentations. The second stage was the Speech Recognition Percentage Index (SRPI) test, to which 40 dBHL was added above the tritone mean, at a fixed intensity, or one that was more comfortable for the subject. For this test, 25 words were presented to the subject, who had to repeat them, and each hit corresponded to 4%. Speech recognition was considered to be within the normal range when the percentage of correct answers exceeded 90%¹¹.
- **Acoustic immittance measurements:** carried out using an *Interacoustics* AT235 device and TDH-39 headphones with a 226 Hz probe¹³. They were classified as normal curves, i.e. normal mobility of the tympano-ossicular system (type A), when they showed values for volume between 0.30 and 1.65 ml and for pressure between 0 daPa and -100 daPa. Contralateral acoustic reflexes

were investigated at frequencies of 500, 1000, 2000 and 4000Hz, and were considered to be present and normal when triggered at differentials between 70 and 100 dB above the afferent airway threshold¹¹.

Central auditory processing assessment

The CAP assessment consisted of a self-perception scale and tests to assess auditory skills. These are detailed below:

Central Auditory Processing Ability Self-Perception Scale (CATAS): this test aims to screen auditory abilities, measuring auditory performance in everyday life. It was administered before the CAP, and the 21 questions were read out to the individual, asking for their answers: “yes” - worth one point or “no” - worth 0 points, and the individual was asked if they went to public school (adding one point to the total score). Finally, they were added together to analyze the total score. For the analysis of the test, normality was considered with scores of less than 4 points, greater than or equal to 5, suggestive of an alteration in auditory closure ability and scores greater than or equal to 6 suggestive of an alteration in temporal resolution ability¹².

To assess hearing ability, all the behavioral tests were conducted in an acoustically treated booth, using Telephonics model TDH39 supra-aural headphones connected to an Interacoustics model AD629B two-channel audiometer, which in turn was connected to a notebook to guide the assessments.

The tests were carried out at an intensity of 40 dBNS above the tritonal mean, applied alternately so as not to be influenced by the participants' fatigue. It should be noted that applying all the tests at the intensity mentioned is feasible, considering the guidelines of regulatory bodies which suggest the use of 40 dBNS above the tritonal mean, a technique also adopted in the IPRF¹³. However, this approach should be re-evaluated in cases of individuals with reduced peripheral hearing acuity. The tests were carried out in a single session, with rest breaks when necessary. Lower performance in at least one of the tests was considered a Central Auditory Processing Disorder (CAPD)¹⁴.

The following tests were selected to cover the minimum suggested battery, in accordance with the recommendations of the American Speech Language-Hearing Association - ASHA¹⁴:

- **Digit dichotic test (DDT):** used to assess figure-ground auditory ability for verbal sounds in the binaural integration stage. The participant was instructed to repeat the four numbers presented simultaneously, two in each ear, at the end of each sequence, regardless of the order. To calculate the final percentage of correct answers per ear, the errors made were added up, the total multiplied by 2.5% and then subtracted from 100 to obtain the percentage of correct answers. Values equal to or greater than 95% were considered normal¹⁵.
- **Frequency Pattern Test (TPF)-auditec:** this was carried out to assess the auditory ability of temporal ordering of non-verbal sounds. The participant was instructed to listen to three stimuli and then reproduce the sequence of frequencies perceived, indicating whether the sound was “thin” or “thick” (example: thin-thin-thick). The analysis of the final percentage of correct answers considered results equal to or greater than 86.6% to be normal¹⁶.
- **Masking Level Difference (MLD):** used to assess the auditory ability of binaural interaction and selective attention. The participant was instructed to answer “no” when hearing only the noise or hiss and “yes” when perceiving the sound of the whistle. The analysis of the final percentage of correct answers used normal values equal to or greater than 8 dB as a reference¹⁶.
- **Speech in noise test (SR):** carried out to assess auditory closure ability for verbal sounds. 25 monosyllable words were presented in each ear, accompanied by ipsilateral white noise, with a signal-to-noise ratio (S/N) of 5 dB. The participant was instructed to ignore the noise and repeat the words heard. The normality criterion adopted was a performance equal to or greater than 70% correct in both ears¹⁵.
- **Gap in noise (GIN):** its purpose was to assess auditory temporal resolution skills. The participant was instructed to raise their hand whenever they identified silence between stimuli. To calculate the percentage of correct answers, the gap detection threshold was taken to be the shortest interval perceived by the individual in at least 4/6 of the presentations. The normal value adopted was ≤ 5 ms. Only track 1 was used in both ears in order to optimize application time¹⁷.

Cognitive assessment

- **Brief Neuropsychological Assessment Instrument (NEUPSILIN):** applied with the aim of providing a brief, quantitative and qualitative neuropsychological profile, by identifying the preservation or impairment of neuropsychological abilities. This procedure consists of 32 subtests, which aim to assess nine cognitive functions: Temporospatial Orientation, Attention, Perception, Memory, Arithmetic Skills, Oral and Written Language, Praxis and Executive Functions. For the present study, taking into account the influence of attentional and memory aspects in eliciting the LLAEP¹⁸, only the attention and memory subtasks were performed and analyzed. The normality criteria used were those of FONSECA, SALLES and PARENTE (2009)¹⁹, taking into account the normative parameters for the average age and schooling of the population studied.

Electrophysiological assessment of hearing:

Before the electrophysiological procedures began, the participants' skin was sanitized in the electrode insertion areas using an abrasive paste. Disposable electrodes were then attached to the specific points. Smart EP equipment from *Intelligent Hearing Systems* (IHS) was used. The impedance of the electrodes was kept below 3 kilohms (k Ω), while the impedance between the electrodes was kept below 2 k Ω . The transducer used was the ER-3A model for both types of potential. This evaluation consisted of the following potentials:

- **Click Brainstem Auditory Evoked Potential (click BAEP):** carried out to check the integrity of the auditory pathway at brainstem level. For the test, the electrodes were positioned at Fpz, Fz, A1 and A2. The stimulus used was a 100ms click, with rarefied polarity and an intensity of 80 dBHL. A total of 2,048 stimuli were presented, at a speed of 27.7/second, a gain of 100.0K and a band-pass filter of 100-3,000Hz, with a recording window of 12ms. Auditory pathway synchrony was considered normal when the latency values of waves I, III and V, their interpeak intervals I-III, III-V and I-V, the interaural difference of wave V and the ratio of waves V/I showed values within the reference standards. The parameters and standard of normality used will be those suggested by Webster (2017)²⁰ using two standard

deviations. During this procedure, the subject kept their eyes closed and relaxed.

- **Long Latency Auditory Evoked Potential - verbal (LLAEP-verbal):** applied in order to obtain information on the neural functioning of the CNS, as well as to carry out the BIC analysis. The electrodes were positioned at points Fpz, A1, A2 and Cz. 150 verbal stimuli (*sweeps*) were applied at an intensity of 70 ndBHL, consisting of the syllable /ba/, which represented the frequent stimulus (80% of the time - 120 stimuli), and the syllable /di/, which represented the rare stimulus (20% of the time - 30 stimuli), in the traditional *oddball* paradigm. The stimulus speed will be 1.1/sec, with a 1-30 Hz filter, 100K gain and a 510 ms time window.

The ears will be investigated monaurally and binaurally. Two waves will be generated from the stimulation: a frequent wave and a rare wave. The N1, P1, N2, P2 and P300 components were marked only in the rare tracing, the right monaural stimulation, the left monaural stimulation and the binaural elicitation waves. The amplitude was measured from the positive peak to the next negative valley. The subjects were instructed to remain alert and pay attention to the "rare" stimuli and to count these mentally perceived stimuli, as this form of counting provides more robust responses to neural functioning.

The reference values used for latency and amplitude were those proposed by BRUNO et al., (2016)²¹, using 2 standard deviations.

Research procedures:

Binaural Interaction Component (BIC)

After capturing the LLAEP-verbal waves in mono and binaural presentation modes, the BIC was generated. To do this, it was necessary to capture the waves in different presentation modes (mono and binaural) and then apply them in arithmetic form. This addition and subtraction of the waves was done in the IHS itself. The program allows you to generate these waves by selecting the "Process" tab, "Add selected (+ Key)" for mono and binaural summation and "Subtract selected (- Key)" for subtraction.

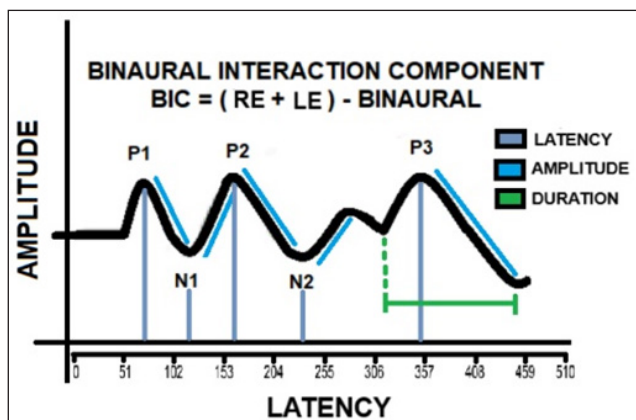
In this study, only rare tracings were used to perform the BIC. Thus, the waves are subjected to the following formula: BIC= wave resulting from monaural stimulation tracings (OD + OE) - wave

resulting from binaural stimulation tracings (DO-BIE and BERLIN (1979)²².

The latency and amplitude of the P1, N1, P2, N2 and P3 components of the BIC were marked

and the P3 duration analysis was included (from the moment the potential begins until it is established in milliseconds).

Figure 1 shows an example of BIC marking.



Legend: BIC= binaural interaction component; OD=right ear; OE=left ear.

Figure 1. Graphical representation of the BIC marking.

After acquisition, the tracings were sent unmarked to two expert judges with PhDs and expertise in LLAEP-verbal, for marking, and the tracings were only considered when there was 100% agreement. If there was no agreement, the traces were sent to a third expert judge to select the component's marking location.

Data analysis

The data was entered into an excel spreadsheet for later descriptive analysis.

Results

Table 1 shows the descriptive values acquired in the BIC-verbal for the cortical-mystical-cognitive components.

Table 1. Description of BIC-verbal values.

BIC components	Mean $\pm$ Standard deviation	Minimum - Maximum
P1 latency (ms)	60.60 $\pm$ 16.26	37 - 82
P1 amplitude (μ V)	1.68 $\pm$ 1.26	0.39 - 3.77
N1 latency (ms)	115.00 $\pm$ 39.50	57 - 208
N1 amplitude (μ V)	2.08 $\pm$ 1.93	0.16 - 5.34
P2 latency (ms)	194.00 $\pm$ 38.86	133 - 256
P2 amplitude (μ V)	2.37 $\pm$ 1.47	0.26 - 5.41
N2 latency (ms)	273 $\pm$ 32.12	230 - 320
N2 amplitude (μ V)	1.92 $\pm$ 1.34	0.16 - 3.78
P3 latency (ms)	361.10 $\pm$ 36.71	288 - 424
P3 amplitude (μ V)	2.25 $\pm$ 1.15	0.48 - 3.78
P3 durations (ms)	114.20 $\pm$ 41.97	70 - 180

Legend: BIC= binaural Interaction Component; ms = milliseconds; μ V = microvolts.

Figure 2 shows the morphology of the BIC tracings of the 10 individuals who took part in the study.

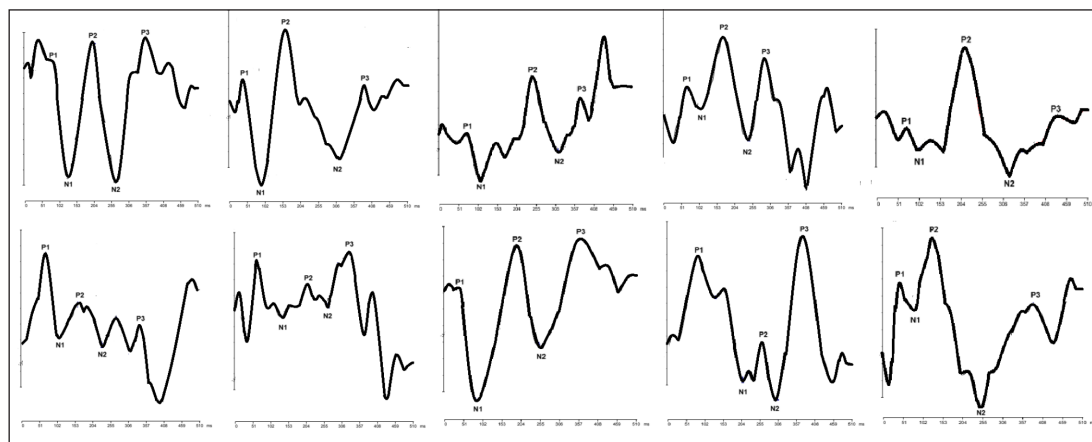


Figure 2. Graphical representation of the tracings obtained in the LLAEP-verbal BIC by subject (n=10).

Discussion

A study that sought to standardize the latency and amplitude values of short, medium and long latency auditory evoked potential in adults used a small sample, but was able to generate the desired reference values²³. In this sense, when describing the BIC values in this study, the small sample size can be justified and representative as a direction for future research. Another aspect refers to methodological rigidity, since by using various assessment instruments to control a typical group with a low standard deviation, a small sample tends to be sufficiently representative, even if it is small.

There are no recent studies in specialized literature that have measured BI using LLAEP with verbal stimuli in typical young adults. However, when comparing the reference values proposed by authors for the LLAEP-verbal, acquired binaurally and without measurement of BI, with the same protocol used in the present study, it is clear that the cortical-cognitive BIC showed higher latencies and lower amplitudes²¹. This may be because the BIC formula generates more specific responses, reflecting the electrical activity of specifically binaural neurons, requiring analysis.

McPherson (1993)⁵ investigated BIC in individuals with normal hearing using rarefied *click*

stimuli. The results indicated that the BIC in long latency potential has two negative peaks (83 ms and 38uV; 234 ms and 25uV) and one positive peak (152 ms and 50uV). In the present study, latency values were close to 100% for all potentials. This can be explained by the stimulus used, since the speech stimulus provides more robust responses, facilitating analysis²⁴. In addition, with these findings, it can be seen that the BI extends over several milliseconds, mainly due to activity in the thalamocortical portions of the auditory pathways.

Image 2 shows the variability in the morphology of the tracings, even in subjects with similar hearing conditions and characteristics. This may be due to the fact that the LLAEP shows the individual behavior of the subject and may present differences in acquisition between and within subjects. Variability in latency values and wave morphology have already been reported by authors⁶, demonstrating that cortical-cognitive binaurality is variable, given the regions that elicit the LLAEP and the need for aspects focused on the mixed and cognitive components (N2-P3), i.e. for detection, discrimination, recognition, attention and memory, there may be variability in responses, even in typical subjects.

Regarding the clinical applicability of the LLAEP BIC, a recent study demonstrated the effects of auditory deprivation in children with

recurrent otitis media, showing differences in the cortical BIC when compared to subjects in the control group, concluding that this can be a useful tool for measuring binaural maturation⁷. Another study carried out the LLAEP BIC in subjects with stroke in the left cerebral hemisphere, demonstrating the changes that occur in binaural responsiveness, more specifically in N1, which is justified because this component is a biomarker of linguistic processing²⁵. Therefore, even though this was not the aim of the study and such comparisons were not made, they seem to be different from the values found in the present study, demonstrating that the BIC has specific values for subjects who are typical of those with alterations or impairments in the maturation of the SNAC, requiring descriptive values.

Heinkin *et al.* (2015) demonstrated that it can be an objective measure of cortical binaural processing, with the potential to become an attractive neural correlate of binaural behavioral performance, there is a need for normative studies, especially in young adults, to help measure binaural neural processes in different populations⁶. This highlights the need to describe the values found.

Therefore, this study shows something new for speech therapy and ENT clinics, given the need to use behavioral methods combined with objective methods. This association is highly relevant, as there is a need to correlate capacity, i.e. the neural substrate, with the individual's functionality¹. In this way, the study stands out and makes a difference due to the characteristics selected in the sample, measuring the real functioning of the central auditory pathway by excluding any auditory, otological, cognitive and/or pre-existing disease variables that could influence the test findings.

The measurement of BIC is justified by the possibility of analyzing it in the diagnosis of auditory deficits or as a therapeutic biomarker, since it is related to specific regions of the auditory-cognitive pathway and can demonstrate which system is more affected (auditory and/or cognitive) and the strategies chosen with greater therapeutic assertiveness (auditory training or auditory-cognitive training).

It is noteworthy that no studies were found in the specialized literature that carried out a behavioral assessment of CAP in young adults and described the BIC of the LLAEP-verbal. In this sense, the potential of this study is highlighted, since understanding binaural functioning in typical young adults makes it possible to understand

the neurophysiological mechanism of the cortical and cognitive binaural auditory pathway, as well as making it possible to extend research, and this metric can be expanded to different populations.

One limitation of the study is the small sample size, but this is justified by the methodology used and the initial objective of describing values. In this way, the present study, due to its novelty, can be considered a guide for future research. The description of BIC values in typical subjects fills a significant gap in the literature, offering the standardization of this data and allowing it to be expanded to populations with auditory or neurophysiological alterations.

Conclusion

It was possible to describe the values of the Binaural Interaction Component of the Long Latency Auditory Evoked Potential - verbal, in the SmartEP - IHS equipment.

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