Development of P1 cortical auditory evoked potential in children presented with sensorineural hearing loss following cochlear implantation: a longitudinal study

Desenvolvimento do potencial evocado auditivo cortical P1 em crianças com perda auditiva sensorioneural após o implante coclear: estudo longitudinal

ABSTRACT

Purpose: To assess the characteristics of P1 component in children presented with pre-lingual hearing loss, users of cochlear implants, and correlate them with speech perception performance. Methods: Ten children presented with pre-lingual sensory neural hearing loss using cochlear implants participated in this research. The cortical auditory evoked potential research was carried out with the /da/ speech stimulus, presented in free field, in three moments: at cochlear implant activation, with three and six months following activation. The Infant-Toddler Meaningful Auditory Integration Scale was used to verify the speech perception. Results: The correlation of the three moments of the test with the latency and the amplitude of P1 component through analysis of variance were observed. The comparison of latency and amplitude of P1 in each assessment moment was performed with Tukey’s test. Wilcoxon and t-test showed that the score on the Infant-Toddler Meaningful Auditory Integration Scale increased significantly with the time of cochlear implant use, nevertheless with no correlation with the latency and amplitude of P1 component in the moments assessed, as demonstrated by Spearman’s and Pearson’s correlations. Conclusion: The latency and amplitude of P1 component diminish as the time of cochlear implant use increases. However, there was no correlation between its development and speech perception performance.

RESUMO


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INTRODUCTION

In the first years of life, an individual’s central auditory system goes through a sensitive period of development. Sensory deprivation, consequential of hearing losses, in this period can alter or prevent central auditory development\(^1\), which prompts cortical reorganization. In this scenario, auditory structures, initially responsible for auditory functioning, respond to other sensory stimuli, such as those of visual nature, for instance\(^2\).

Alternatively, the introduction of auditory stimulation through electronic devices, such as cochlear implants, in individuals with more accentuated hearing losses can partially or totally revert the effects of this sensory deprivation and redirect these structures to their primary function. Consequently, the development of auditory abilities, a prerequisite for oral language acquisition and production, is also enabled\(^3\).

The changes that occur in central auditory pathways, after the activation of cochlear implants, can be verified by means of electrophysiological procedures. The study of cortical auditory evoked potentials (CAEP) allows for the analysis of the responses of electrically stimulated central auditory structures, and it does not depend on a child’s attention span and behavioural responses. For this reason, it is a reliable measure of an individual’s maturational process and cortical auditory functioning.

The P1 component of CAEP has been most utilized in research because it is considered a biomarker of the maturation of the auditory system structures. Individuals using cochlear implants for a longer time show lower latency for the P1 component\(^4,7\). In addition, the development of the P1 component follows the same pattern as that of a child with typical hearing, but with delays in the maturational process\(^5,8\). However, recent studies have shown that the P1 component has quick effects following the activation of cochlear implants, reaching normality values between three and eight months from the beginning of the use of this device\(^7,9,12\).

The time span of auditory sensory deprivation influences the process of central maturation\(^0,13,14\). Children who receive cochlear implants after the sensitive period can present abnormal cortical auditory responses, even after many years of auditory stimulation\(^0,14,15\).

Moreover, individuals with poorer speech perception present atypical records concerning these potentials\(^16,18\), thus reflecting abnormal or immature patterns in cortical activity\(^16\).

Therefore, by studying the maturational process of the auditory system, with a focus on CAEP in children who received cochlear implants, it is possible to obtain important information that can aid in understanding the differences in the speech perception development observed among users of cochlear implants, and, consequently, reflect upon the process of referring individuals to this implantation, especially with regard to a child’s age at the time of the procedure.

The aim of this study was to analyze the characteristics of the P1 component in children with prelingual hearing loss, who received cochlear implants, and correlate them with speech perception development.

METHODS

The present study was approved by USP’s Ethics Committee, as per report number 181/2004. The patients’ legal guardians signed the Informed Consent prior to the conduction of the examination.

Ten children participated in this study. They met the following criteria: age range between 1 and 5 years, and use of cochlear implants with profound bilateral prelingual sensory neural hearing loss. Children with neurological alterations and/or compromised auditory nerves attested by magnetic resonance imaging were excluded from this study.

Chart 1 presents the sample’s characteristics in relation to etiology, age at the time of activation, model of the internal component, speech processor, and signal processing strategy.

We assessed the children by investigating the CAEP in three stages: at the moment of cochlear implant activation, at three months, and at six months after the implantation, according to the methodology used in a previous study carried out in our laboratory\(^19\).

The assessment of the CAEP was performed with the Smart EP USB programme, by Intelligent Hearing Systems. The auditory potentials were registered on channel A, and the ocular and blinking movements, on channel B.

<table>
<thead>
<tr>
<th>Patient</th>
<th>Etiology</th>
<th>Age at activation</th>
<th>Internal component model</th>
<th>Speech processor</th>
<th>Signal processing strategy</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Cytomegalovirus</td>
<td>3 y 1 m</td>
<td>SONATA Ti100</td>
<td>Opus 2</td>
<td>FS4</td>
</tr>
<tr>
<td>2</td>
<td>Idiopathic</td>
<td>2 y 3 m</td>
<td>Hires 90k</td>
<td>Harmony</td>
<td>Hires</td>
</tr>
<tr>
<td>3</td>
<td>Genetic</td>
<td>2 y 6 m</td>
<td>Hires 90k</td>
<td>Harmony</td>
<td>Hires-P w/Fidelity</td>
</tr>
<tr>
<td>4</td>
<td>Consanguinity</td>
<td>1 y 2 m</td>
<td>Hires 90k</td>
<td>Harmony</td>
<td>Hires-P w/Fidelity</td>
</tr>
<tr>
<td>5</td>
<td>Genetic</td>
<td>4 y 3 m</td>
<td>Hires 90k</td>
<td>Harmony</td>
<td>Hires-P w/Fidelity</td>
</tr>
<tr>
<td>6</td>
<td>Idiopathic</td>
<td>2 y 1 m</td>
<td>Hires 90k</td>
<td>Harmony</td>
<td>Hires-P w/Fidelity</td>
</tr>
<tr>
<td>7</td>
<td>Consanguinity</td>
<td>2 y 5 m</td>
<td>Hires 90k</td>
<td>Harmony</td>
<td>Hires-P w/Fidelity</td>
</tr>
<tr>
<td>8</td>
<td>Idiopathic</td>
<td>1 y 10 m</td>
<td>SONATA Ti100</td>
<td>Opus 2</td>
<td>FS4</td>
</tr>
<tr>
<td>9</td>
<td>Idiopathic</td>
<td>3 y 1 m</td>
<td>SONATA Ti100</td>
<td>Opus 2</td>
<td>FS4</td>
</tr>
<tr>
<td>10</td>
<td>Idiopathic</td>
<td>1 y 6 m</td>
<td>SONATA Ti100</td>
<td>Opus 2</td>
<td>FS4</td>
</tr>
</tbody>
</table>

Caption: y = years; m = months.
In channel A, the active electrode was positioned in Cz connected to the (+) input of the pre-amplifier, and the reference electrode was positioned in the mastoid contralateral to the cochlear implant, connected to the (-) input. The ground electrode was placed in Fpz, connected to the ground position. In channel B, the active electrode was placed in the supraorbital position, contralateral to the cochlear implant connected to the (+) input of the pre-amplifier, and the reference electrode was placed in the infraorbital position on the same side, connected to the (-) input. With the electrodes disposed in this manner, we monitored ocular movement and delimited the rejection level used in each examination.

In order to register ocular and auditory evoked potentials, we utilized ECG disposable electrodes of the brand Meditract™ 200, with Tem 20TM conductive paste for EEG, set in place after the individuals’ skin was cleaned with Nuprep abrasive gel for ECG/EEG. The impedance level was maintained between 1 and 3 kΩ for the electrodes.

The auditory responses were registered in response to a /da/ speech stimulus in an intensity of 70 dB NA, applied in a previous study[20]. The [da] stimulus was extracted from the second syllable of the word [da‘da], produced by a male young adult with fluid voice quality and recorded by means of a unidirectional microphone with the free programme Praat (www.praat.org) directly onto the computer board at a sampling rate of 22 kHz. The bandwidths were collected from the stable region of the formant frequencies (F1, F2, and F3). With these values, we compiled a script in the Praat (version 4.2.31), and the syllable was resynthetized. The duration of the [da] syllable corresponds to 180 ms. The linguistic stimulus produced, previously manipulated and recorded in a CD, was inserted in unit C of the computer connected to the software, Smart EP USB, by Intelligent Hearing Systems.

The procedure was conducted in free field, with the acoustic box positioned at the child’s head level at a distance of 40 cm and azimuth 90°. We used a 30 W RMS power amplifier and a 50W RMS acoustic box on a tripod. An isolation transformer was installed in the amplifier’s passive signal input, with an impedance input of 440 Ω (impedance identical to that of the earphones used in the test). The signal output of the earphones used in the test, was installed in the amplifier’s passive signal input, with a signal input of 440 Ω (impedance identical to that of the earphones). The level of significance adopted was 5%.

The descriptive analysis of the sample with regard to the children’s age at the moment of cochlear implant activation, latency and amplitude values of the P1 component, and the IT-MAIS score in the three stages of assessment is presented in Table 1.

Through the application of ANOVA, we found differences in the latency (F=22.4; p=0.00) and amplitude (F=6.25; p=0.00) of the P1 component, according to the stage of assessment. Tukey’s test showed differences in P1’s latency values in the three assessment stages (Activation – three months; three – six months; Activation – six months). On amplitude, we observed differences in the component’s values in the following stages of assessment: Activation- 3 months; and Activation–six months (Table 2).

### RESULTS

The descriptive analysis of the sample with regard to the participants’ age at cochlear implant activation, P1 latency (milliseconds), P1 amplitude (µV), and IT-MAIS score (%) in the three moments evaluated through the CoDAS 2013;25(6):521-6

<table>
<thead>
<tr>
<th>Table 1. Descriptive analysis of the sample with regards to the participants’ age at cochlear implant activation, P1 latency (milliseconds), P1 amplitude (µV), and IT-MAIS score (%) in the three moments evaluated</th>
<th>Mean</th>
<th>Median</th>
<th>Min</th>
<th>Max</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age at activation</td>
<td>2 y 5 m</td>
<td>2 y 4 m</td>
<td>1 y 2 m</td>
<td>4 y 3 m</td>
<td>0.89</td>
</tr>
<tr>
<td>Latency at activation</td>
<td>313.80</td>
<td>305.50</td>
<td>290.00</td>
<td>365.00</td>
<td>23.93</td>
</tr>
<tr>
<td>Latency at 3 m</td>
<td>259.70</td>
<td>280.00</td>
<td>163.00</td>
<td>311.00</td>
<td>57.44</td>
</tr>
<tr>
<td>Latency at 6 m</td>
<td>177.80</td>
<td>150.00</td>
<td>99.00</td>
<td>275.00</td>
<td>69.41</td>
</tr>
<tr>
<td>Amplitude at activation</td>
<td>4.85</td>
<td>4.72</td>
<td>1.58</td>
<td>8.77</td>
<td>2.23</td>
</tr>
<tr>
<td>Amplitude at 3 m</td>
<td>2.46</td>
<td>2.38</td>
<td>1.12</td>
<td>5.13</td>
<td>1.20</td>
</tr>
<tr>
<td>Amplitude at 6 m</td>
<td>3.05</td>
<td>3.32</td>
<td>1.27</td>
<td>4.92</td>
<td>1.38</td>
</tr>
<tr>
<td>IT-MAIS at activation</td>
<td>&lt;25.00</td>
<td>&lt;25.00</td>
<td>&lt;25.00</td>
<td>&lt;25.00</td>
<td>–</td>
</tr>
<tr>
<td>IT-MAIS at 3 m</td>
<td>54.75</td>
<td>60.00</td>
<td>15.00</td>
<td>5.00</td>
<td>18.54</td>
</tr>
<tr>
<td>IT-MAIS at 6 m</td>
<td>75.50</td>
<td>75.00</td>
<td>40.00</td>
<td>100.00</td>
<td>19.32</td>
</tr>
</tbody>
</table>

**Caption:** P1 = P1 cortical auditory evoked potential; Min = minimum; Max = maximum; SD = standard deviation; y = years; m = months.

<table>
<thead>
<tr>
<th>Table 2. Comparative statistical analysis of the component’s latency and amplitude at the three evaluation moments</th>
<th>3 months</th>
<th>6 months</th>
</tr>
</thead>
<tbody>
<tr>
<td>Latency</td>
<td>Activation</td>
<td>0.04*</td>
</tr>
<tr>
<td></td>
<td>3 months</td>
<td>–</td>
</tr>
<tr>
<td>Amplitude</td>
<td>Activation</td>
<td>0.00*</td>
</tr>
<tr>
<td></td>
<td>3 months</td>
<td>–</td>
</tr>
</tbody>
</table>

*Significant values (p<0.05) – Tukey’s Test.
The P1 component of CAEP was identified in all children in the three moments of assessment, with changes in morphology (Figure 1). The development of the P1 component in each individual is illustrated in Graph 1.

The IT-MAIS scores increased significantly with the time of use of the cochlear implant (Table 3), but there was no correlation with P1’s latency and amplitude in the three moments evaluated (Table 4).

**DISCUSSION**

As the time of cochlear implant use lengthens, a decrease in latency and amplitude of the P1 component is expected in children with prelingual sensory hearing loss\(^{(4,7,9-12,15,22)}\). Our findings corroborate those found in the literature, given that the latency and amplitude decreased.
defined with the maturational process\(^{(4,13)}\). This finding was characterized as a prominent positive peak that is gradually registered in all children. At this moment, the P1 component activation of the cochlear implants, as the P1 component was previously described in children with Auditory Neuropathy Spectrum Disorder, who used Hearing Aids (HA)\(^{(23)}\).

A quick rate of P1 development following the activation of cochlear implants in children operated during the sensitive period, that is, up to three years and six months of age, has been described in literature. In these studies, the P1 component reached normal latency values between three and eight months after the implantation of the device\(^{(7,8,11,12)}\). According to Graph 1, in the period of six months of cochlear implant use, the course of the maturational process of the auditory system occurred as expected, with the exception of patient 8, in whom there was no reduction in P1 latency in comparison to the second and third stages of the assessment. Upon further analysis of the patient’s history, we attested that the anatomic conditions found at the moment of surgery prevented cochlear implantation in the ear determined initially. The doctors’ immediate conduct was to implant the device in the opposite ear, which later resulted in the lack of use of a HA in the ear contralateral to the cochlear implant.

In addition, three children presented P1 components with the expected latency for their chronological age despite the shorter time of auditory experience, which indicates quicker P1 development. Possibly, the stimulation of the cochlear implant during the sensitive period initiates an atypical and widespread pattern of activation of different cortical layers, resulting in a more rapidly decrease in latency than those found in children with typical hearing\(^{(12)}\).

It is known that the time length of auditory sensory deprivation that precedes the activation of cochlear implants considerably influences the redirecting of structures of central auditory pathways toward their primary function. This could explain the variability of the component P1’s latency and amplitude, and, consequently, the interference with speech perception. After the period considered sensitive, the benefits of cochlear implantation in relation to speech perception tend to diminish with the advancing of an individual’s age at the moment of activation\(^{(5,9)}\).

In this study, only one child received the cochlear implant after this period (patient 5, at 4 years and 3 months of age). However, we verified that the development of the P1 component was similar to that of patients 1, 3, 7, 9, and 10. It is also possible to attest differences in this developmental process, probably justified by the fact that the activation of cochlear implants is not the only determining factor, but also the quantity and the quality of auditory stimulation\(^{(24)}\). This fact has already been reported in studies on the development of auditory abilities considered as prerequisites for oral language acquisition and development. In those studies, the time of device use and aspects related to the family and auditory rehabilitation are shown to have an impact on the benefits obtained through cochlear implants\(^{(24-27)}\).

Previous studies have described the correlation between the P1 component and an individual’s performance in tests of auditory abilities, characterizing this component as a predictor of the development of speech auditory perception\(^{(16-18,23,29)}\).

In this study, there was significant improvement in the individuals’ auditory abilities with the use of cochlear implants, assessed through the IT-MAIS questionnaire (Table 3), but no significant correlation with the latency and amplitude of the P1 component (Table 4). This finding, which diverges from other studies in the literature, can be justified by the fact that the children in the present study had a maximum time of device use of six months. Moreover, the auditory abilities assessed through this questionnaire, although considered as initial stages in the process of auditory functioning development, are completely acquired approximately only after one year of device use, represented by a score of 80 to 100%\(^{(30)}\).

The results of this study corroborate other findings in the literature in the sense that the redirecting of central structures by means of cochlear implant stimulation can be followed after the period of sensory deprivation through the investigation of CAEP, which proved to be a procedure that can be applied in clinical practice. These findings can contribute to the guidelines for cochlear implantation referrals in infants, thus directing public policies concerning auditory deficiency treatment. In addition, we reaffirm that surgeries performed in the ideal period are not sufficient to guarantee an individual’s good performance with the use of cochlear implants, as therapeutic intervention and continuous patient monitoring are also necessary.

**CONCLUSION**

The latency and amplitude of the P1 component decrease as the time of use of cochlear implants increase. However, there was no correlation between its development and speech perception performance.

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* KFA was responsible for the research and design of the study, the general direction of the stages of the execution, supervision of data collection, analysis and interpretation of data and preparation, submission and final approval of the manuscript; LCV collaborated with the collection, tabulation, analysis and data interpretation and assisted in the preparation and submission of the manuscript; RCFL collaborated with the data collection, analysis and interpretation; LMPV contributed to the collection, analysis and interpretation of data; MCB collaborated with the analysis and interpretation of data and helped in the preparation of the manuscript; ALMM contributed to the analysis and interpretation of data and in the preparation of the manuscript.
REFERENCES