

Original Article

Development of Aided Long-Latency Response (ALLR) in Children With Cochlear Implant Within 18 Months of Implantation

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OBJECTIVES: This study investigated the development of aided long-latency response (ALLR) in children with cochlear implants (CI) within 18 months of implantation.

MATERIALS AND METHODS: ALLR was recorded in 33 children with CI who had an experience of less than 18 months with the implant. All the participants were in the age range of 3-7 years and were divided into 3 groups based on implant age, as 0-6 months, 6.1-12 months, and 12.1-18 months. Latency of the P1 component was recorded.

RESULTS: P1 latency was observed to be 142.105 ms at 0-6 months of implant age, 135.141 ms at 6.1-12 months of implant age, and 122.952 ms at 12.1-18 months of implantation. CI recipients require 1 year of experience in order to obtain a significant difference in the P1 latency value. It was also found that gender does not influence P1 latency.

CONCLUSION: These preliminary findings suggest that with adequate stimulation, there is a gradual decrease in P1 latency, which indicates maturation of the central auditory structures. It was also found that the gender does not influence P1 latency.

INTRODUCTION

The auditory pathway continues to develop from birth to adolescence.¹ Auditory evoked potentials are recorded noninvasively from all levels of the central auditory pathways and can provide objective assessments of the development and functioning of the auditory nervous system in young children. Long-latency responses (LLR) can be used to monitor the developmental trends in the auditory cortex in individuals with normal hearing as well as in other clinical populations, including those with hearing impairment. Maturation of the cortical structures is highly dependent on auditory stimulation. The introduction of amplification systems such as hearing aids and cochlear implant (CI) has helped in reducing the auditory deprivation caused due to deafness and in developing adequate auditory, speech, and language skills. Auditory deprivation limits cortical maturation and plasticity. Thus, auditory responses are either delayed or absent in individuals with hearing impairment.² Cochlear implantation helps an individual by giving adequate stimulation, thereby enhancing auditory development. LLR measured with an amplification system called aided long-latency responses (ALLR) is widely used in determining the efficacy of the hearing aid and cochlear implant. The P1 latency was reduced in cochlear-implanted recipients, with increasing auditory experience time.³⁻⁵ Due to this, P1 latency has been used as an index of maturation of the auditory pathway in populations with abnormal auditory experience.^{4,6,7} Although much research has been done on the development of cortical structures using LLR, information regarding the changes in ALLR within a limited time period of implantation, and the expected P1 latency with increasing implant age in the chronological age range of 3-7 years is limited. Thus, the current study looks into the developmental changes in the ALLR in children, by studying CI recipients within 18 months of implantation.

MATERIALS AND METHODS

The test procedure was carried out after getting an informed consent letter from the parents of children with CI.

Participants

Thirty-three participants fitted with CI were recruited for the study. The sample comprised of 17 males and 16 females. Thirty two participants were implanted with CI24RE and fitted with a CP802 sound processor from Cochlear Corporation, and 1 participant was implanted with SONATA100 and fitted with an OPUS 2 sound processor from Med-EL Corporation. The participants included in the study were Kannada speakers and were divided into 3 groups based on their implant age. The groups were as follows, group 1 consisted of 12 participants with an implant age of 0-6 months, group 2 consisted of 8 participants with an implant age of 6.1-12 months, and group 3 consisted of 13 participants with an implant age of 12.1-18 months. The participants from all groups in the study met the following inclusion criteria: pre-lingually hearing impaired, age at the time of testing between 3 and 7 years (mean age: 5.6 years), consistent CI users, received CI before 7 years of age, and less than 18 months of hearing experience with their device. Participants with intellectual or cognitive deficits, inner ear malformation, cochlear nerve deficiency, and other co-morbid conditions were excluded from the study.

Instruction

The participants were instructed to lie down in the supine position on the bed where they would be hearing a speech sound /da/. They were also asked to avoid movement of extremities at the time of testing. To ensure that they remain alert, they were allowed to watch cartoons of their interest with no audio output.

Electrode Placement

The placement sites were cleaned by rubbing the surface with cotton using Nu-Prep gel. Three disc electrodes were kept on the appropriate sites of generation based on the international 10/20 placement system (Jasper, 1958), using a conduction gel. The electrode was secured in place by a piece of plaster. The non-inverting electrode was placed at the Cz, the inverting electrode was placed on the contralateral mastoid with respect to the ear implanted, and the ground electrode was placed on the forehead in Fpz.⁶ Electrode impedance was checked and was less than 5kohms throughout the recording. Electrode placement was cleaned again to get adequate impedance if necessary.

Details of the Stimulus

Long-latency response was recorded in response to the speech stimulus/da/. The duration of stimuli was 100 ms. Center frequencies of

the formants F1, F2, F3 and F4 were 883.78 Hz, 1584.32 Hz, 2706.02 Hz and 4050.62 Hz respectively. The mean fundamental frequency of the stimulus was found to be 321.959 Hz. The stimulus was delivered using an ER3A insert earphones connected to the Biologic Navigator Pro AEP system. The level of the stimulus reaching the ear was maintained at 70 dB SPL, and was monitored using a sound level meter kept in the ear level. Details are given in the next section.

Evoked Response Recording Procedure

During the recording procedure, children lay on the bed in the supine position in a sound-attenuated booth. The children were allowed to watch a cartoon of interest with no audio output. This was found to be an effective way of keeping children engaged while recording ALLR.^{8,9} For the presentation of speech stimuli, the insert ear phone was kept at a distance of 2 cm away and at 90° azimuth with respect to the microphone of the speech processor. The level of stimuli was kept constant at 70 dB SPL and was monitored using Bruel & Kajer modular precision sound level meter type 2231 kept at the ear level. The evoked responses were recorded using silver electrodes placed on the generation sites, based on the international 10/20 placement system, with the CI processor on. The incoming evoked responses were analog-filtered from 1 to 30 Hz (12 dB/octave), and a gain of 10 000 was applied. The recording window included a 150 ms pre-stimulus period and a 533 ms post-stimulus period. During the testing session, 2 recordings of 200 sweeps were collected. The data were saved to a computer for further analysis. The total testing time including electrode placement was approximately 30 minutes.

Data Analysis

The electroencephalogram (EEG) activity was continuously monitored visually throughout the session for abnormal activities, including extreme muscle activity and external noise. EEG epochs greater than 50 μ V were rejected. The remaining epochs were averaged to compute an average waveform. P1 was marked as the robust positive peak in the wave form. The latency of the P1 peak was noted down. The protocol used in the study is summarized in Table 1.

Statistical Analysis

The details of the data collected were entered into Microsoft Excel version 2007. Statistical analysis was carried out using the software IBM SPSS version 20. Descriptive and inferential analysis was carried out. The data were subjected to the following procedures: descriptive statistics were carried out for P1 latency. As a parametric test, one way ANOVA was done to compare the P1 latency of groups of different implant ages. In order to analyze multiple pair comparison, post hoc analysis (Tukey HSD) was carried out. An independent t test was done to compare the P1 latency between genders. A significance of 5% level was considered.

RESULTS

Comparison of P1 Latency Between Implant Ages

Three implant age groups were compared to find the development of ALLR within 18 months of implantation using one way ANOVA, as shown in the Table 2.

P1 latency, $F(df1, df2)=5.22(2, 31)$ was found to be statistically significant in the 3 implant age groups, $P=.012$. This indicates an

MAIN POINTS

- There is a gradual reduction in P1 latency with adequate stimulation.
- The mean P1 value for children in the age range of 3-7 years was observed to be 142.105 ms at 0-6 months of implant age, 135.141 ms at 6.1-12 months of implant age, and 122.952 ms at 12.1-18 months of implant age.
- There was an overall significant difference in P1 latency between the 3 groups.
- The difference was observed to be more between 0-6 months and 12.1-18 months of implant age, which indicates the need for 1 year of stimulation with CI in order to get a significant difference in ALLR.
- Gender does not influence P1 latency.

Table 1. Protocol Used

Parameters	
Stimuli used	/da/
Duration of stimuli	100 ms
Rate	1.1/s
Intensity	70 dB SPL
Mode of recording	Monaural
Transducer	Insert earphone
Placement	Inverting: Contra lateral mastoid Non-inverting: Cz Ground: Fpz
Polarity	Alternating
Artifact rejection	50 μ
Filtering	1-30 Hz
Amplification	10 000
Analysis time	Pre-stimulus: 150 ms Post-stimulus: 533 ms
Sampling rate	512
No of averages	200
Replication	At least 2

overall difference in P1 latency across implant age groups. The effect of P1 latency in the groups is graphically represented in Figure 1.

There is a gradual reduction in P1 latency with increasing implant age. A value of $P < .05$ indicates an overall difference in the P1 latency of different implant age groups. In order to find multiple pair comparisons between the 3 implant age groups to see which pair of groups showed significant difference in the P1 value, post hoc analysis (Tukey HSD) was carried out. The significance of multiple group comparison is shown in Table 3. The result indicates a significant

difference in the P1 latency between 0-6 months and 12.1-18 months of implantation, with $P = .09$.

The Figure 2 shows the LLR waves of 3 individuals based on their average duration of stimulation with the CI (0-6 months, 6.1-12 months, 12.1-18 months). From the figure, it was revealed that with increase in implant age, there was a systematic change in P1 latency.

Comparison of P1 Latency Between Genders

To determine whether gender influenced P1 latency with increasing implant age, the independent samples t -test was used. The sample consisted of 17 males and 16 females. The result of the analysis was as shown in Table 4.

P1 latency, $t(df) = 0.375(31)$ was not statistically significant between the 2 genders, $P = .71$. However, the P1 latency was found to be lesser in females (132.67 ms) compared to males (134.88 ms), as shown in the Figure 3.

DISCUSSION

Cochlear implantation helps an individual by giving adequate stimulation, thereby enhancing auditory development. The results of the study showed that there was an overall significant difference in P1 latency in the 3 groups. The P1 latency reduced with increasing implant age. The mean P1 value for children in the age range of 3-7 years was observed to be 142.105 ms at 0-6 months of implant age, 135.141 ms at 6.1-12 months of implant age, and 122.952 ms at 12.1-18 months of implant age. There are many studies on changes in LLR latencies in children with CI. They showed a reduction in P1 latency with increasing implant age.^{4,6-9} These results are in accordance with the findings of the current study. This reduction happens due to underlying changes in the auditory cortex with stimulation. Several studies have shown that, there is a high degree of plasticity in the central auditory pathways of congenitally deaf children who were fitted with a CI early in childhood. They infer the presence of plasticity

Table 2. Comparison of P1 Latency in Implant Age

	0-6 Months (N = 12), Mean \pm SD	6.1-12 Months (N = 7), Mean \pm SD	12.1-18 Months (N = 13), Mean \pm SD	P
P1 Latency	142.105 \pm 12.1773	135.141 \pm 10.2539	122.952 \pm 18.9975	.012*

*Significance.

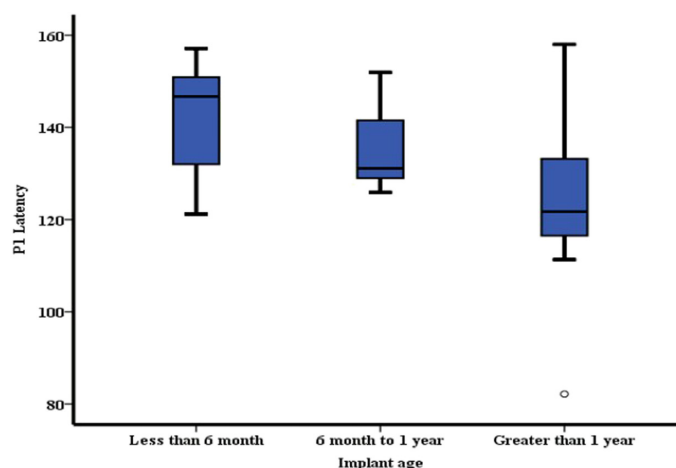
**Figure 1.** Box plot of implant age for P1 latency.

Table 3. Multiple Group Comparison of P1 Latency

Implant Age	Implant Age	Std. Error	Significance
1 to 6 months	6.1 to 12 months	6.5302	.542
	12.1 to 18 months	.9535	.009*
6.1 to 12 months	12.1 to 18 months	6.7526	.186

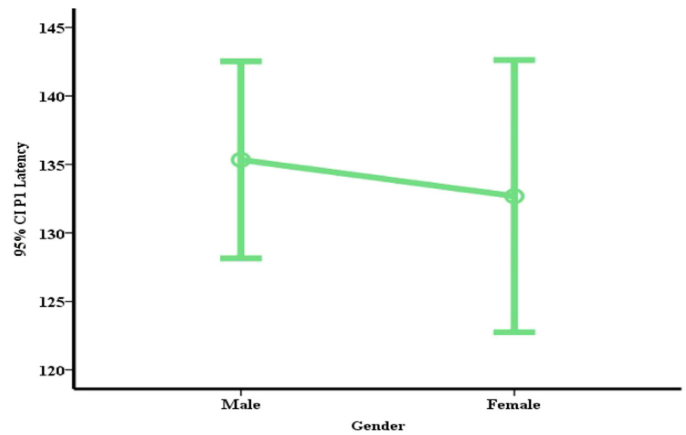
*Significant.

Comparison of P1 Latency Between Genders.

from the rapid alterations in morphology, and the rapid decreases in P1 latency with increasing auditory experience. Because of this, P1 latency has been used as an index of maturation of the auditory pathway in populations with abnormal auditory experience.⁴

Different studies have been done to find out the latency of P1 component. The mean latency in a group of children with a maximum age of 3 years and 5 months who received a CI, was observed to be 137.5 ms after 12 ± 18 months of CI use.⁵ Another study monitored 10 children aged between 1 and 5 years and observed that latency values were 259 and 177 ms after 3 and 6 months of CI use, respectively.¹⁰

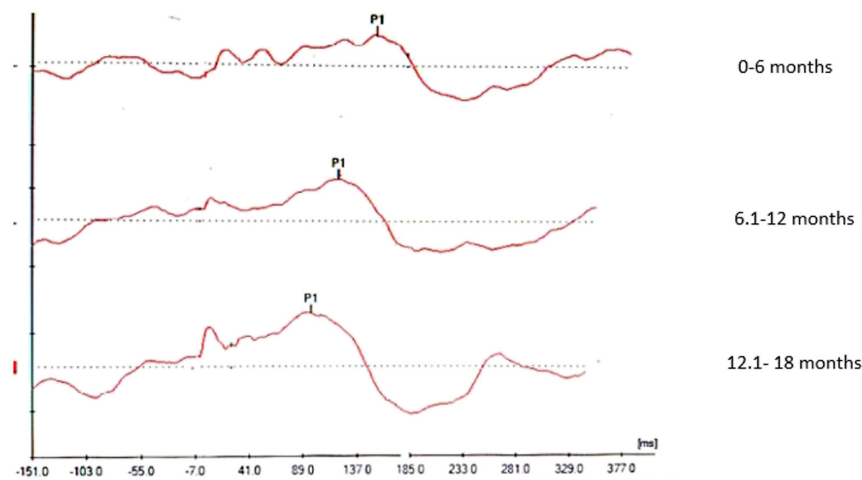
Studies have shown that children implanted before the age of 3.5 years acquired age-appropriate P1 latency within 6 to 8 months of implantation, whereas cases of implantation after 7 years showed a delayed latency suggesting plasticity of auditory system in the early implanted individuals.^{2,6,11} Thus, we can infer that the development of P1 latency depends on the duration of auditory deprivation, and it continues to develop with electrical stimulation given through CI. For individuals with hearing impairment, electrical stimulation reduces the amount of degeneration in the structures and will help in maturation of the auditory system.^{1,12} The presence of ALLR within 1 week of stimulation suggests the cortical reorganization happening in the brain immediately after the implantation.⁶ Eggermont et al.³ indicated that the rate of maturation of P1 latency happens at same rate in normal and implanted children, but the time to maturity is delayed by an amount that is approximately equal to the duration of deafness. In the current study, there was a significant difference with increasing implant age, suggesting cortical reorganization that is shown in a gradual reduction in P1 latency. Overall, there was a difference in P1 latency with increasing implant age, but 1 year of

**Figure 3.** Error plot of P1 latency between genders.**Table 4.** Comparison of P1 latency between genders

	Male (N = 17)		Female (N = 16)		P
	Mean	SD	Mean	SD	
P1 latency	134.88	14.31	132.679	18.6474	.71

experience with the implantation was required to get a significant difference in P1 latency. In the present study, the data obtained from CI recipients were not compared with age-matched children having normal hearing. Therefore, there is no information on P1 latency comparison with age-matched groups.

It was found that gender does not influence P1 latency. A few studies showed an effect of gender in children using CI on speech perception, speech production, language, and reading.^{13,14} Girls with cochlear implantation exhibited higher scores compared to boys. However, studies on the effect of gender on latency in aided LLR are limited. In the population with normal hearing, there were no differences in P1–N1–P2 component latencies and amplitudes between female and male listeners.^{15,16} Another study by Swing & Stuart¹⁷ showed that female participants had significantly shorter latencies for only the P2 component and that gender had no effect on P1 and N1. These results are in accordance with the current findings from this study, showing no gender effect in P1 latency.

**Figure 2.** LLR waveforms of 3 individuals based on different implant ages.

LIMITATION

- The sample size for the study was small. For this study 34 participants were divided into 3 groups based on implant age. Hence, each group consisted of a small sample size.
- The effect of implanted age on development of ALLR was not studied.
- The data obtained in the current study were not compared with age-matched individuals with normal hearing to obtain information regarding the maturational difference between them and to find the duration required to develop age-appropriate measures in CI recipients.

CONCLUSION

ALLR is used to find the developmental changes in auditory structures by comparing the responses obtained. The results of the study showed that there was an overall significant difference in P1 latency in the 3 groups, and the difference was observed to be more between 0-6 months and 12.1-18 months of implant age, which indicates the need of year of stimulation with CI in order to get a significant difference in ALLR. P1 latency reduced with increasing implant age. The mean P1 value for children in the age of 3-7 years was observed to be 142.105 ms at 0-6 months of implant age, 135.141 ms at 6.1-12 months of implant age, and at 12.1-18 months of implant age was 122.952 ms. It was also found that gender does not have an effect on P1 latency. These preliminary findings suggest that with adequate stimulation, there is a gradual decrease in P1 latency, which indicates maturation of the central auditory structure.

Ethics Committee Approval: Approved by the ethical committee of Dr S R Chandrasekhar Institute of Speech and hearing.

Informed Consent: Informed consent taken from all the parents of children with CI.

Peer Review: Externally peer-reviewed.

Author Contributions: Theertha Dinesh K C: Material, Data collection and/or processing, Analysis and/or interpretation, Literature review, Writing Megha Sasidharan : Conception, Design, Supervision, Critical review.

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Conflict of Interest: The authors have no conflict of interest to declare.

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