International Journal of Otorhinolaryngology and Head and Neck Surgery
*Puri N et al. Int J Otorhinolaryngol Head Neck Surg. 2024 Oct;10(5):495-500*
http://www.ijorl.com
pISSN 2454-5929 | eISSN 2454-5937

## Original Research Article

DOI: https://dx.doi.org/10.18203/issn.2454-5929.ijohns20242704

# Working memory capacity in children with early and late cochlear implantation: a P300 evaluation

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**Received:** 03 June 2024
**Accepted:** 23 July 2024

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## ABSTRACT

**Background:** Cochlear Implant helps in improving hearing sensitivity, speech perception and production, cognitive abilities, and enhances academic performances, peer relationships and quality of life. Hearing impaired individuals has reduced working memory capacity and working memory depends on the ability of hearing and processing of information to the brain. P300 act as an electrophysiological test to assess the working memory capacity. The aim of the study was to evaluate the effect of age of cochlear implant on working memory capacity.
**Method:** A total of 30 participants were included in this study, which were divided into two groups. Group 1 consisted of 15 individuals who had done cochlear implant (CI) before 3 years of age. In Group 2, 15 subjects were included who had done their CI after 3 year of age and before 6 years of age. P300 was carried out among these individuals using speech stimulus and the result was compared between groups.
**Result:** The t test value for P300 amplitude (t:10.34, $p<0.05$) and latency (t:4.66, $p<0.05$) indicate that there are statistically significant differences exist between the two groups in terms of P300 amplitude and latency. From the mean value we can conclude that early-implanted individuals have higher amplitude and shorter latency compared to late-implanted individuals.
**Conclusion:** The results of this study have significant ramifications for how the therapeutic strategy for kids with congenital hearing loss is planned. It highlights the need of early action and the crucial timeframe. It assesses the neuromodulation of the brain's auditory regions directly and connects it to the implanted age.

**Keywords:** Cochlear implant, Working memory, P300, Age of implantation, Phonological loop

## INTRODUCTION

Hearing loss generally affects the ability to hear, to discriminate between various sounds and localization of sounds. The congenital hearing impairment or early childhood or prelingual hearing impairments has devastating consequences on the child's language acquisition skills. This impact will result in linguistic delay, hence thereby leading to interference in the development of speech perception and verbal language development and performance. Hearing aid plays an important role in amplifying acoustic stimulus to the cochlea so that hearing impaired person can get benefit from this.[1] In advancing technology, cochlear implant (CI) plays an important role than hearing aids as CI directly stimulate the cochlear hair cells by providing electrically stimulus.[2] CI are technically advanced implantable medical devices at help children and adults who have severe-to-profound hearing loss and do not receive satisfactory benefit from HAs or tactile devices to hear. They are useful to provide better hearing function to profoundly deaf children and adults.[3] They considerably improve speech perception and production, cognitive abilities, and enhances academic performances, peer relationships and quality of life. While some implant users seem to perform almost equivalent to normal-hearing peers on speech perception measures, others perform considerably below average. In comparison to adults and children with normal hearing, CI users' ability to understand speech is still limited. The development of speech, peer-like language, and more general academic skills during childhood, as well as socioemotional skills and day-to-day functioning later in life, may be impacted by age of implant.[4] There are various factors cited for variable outcomes in individuals with CI such as age at implantation, communication mode and Intelligent quotient.[5,6]

The lack of availability of outcome measures for cochlear implants in form of questionnaires, behavioural tests and checklists pose a problem in evaluation of cochlear implant performance in children. Due to the direct electrical stimulation to the cochlea, it is believed and proven in various research that CI can improve the frequency selectivity even in severe to profound hearing-impaired persons. However, the outcomes from CI depend on various factors. Some of the factors are duration of deafness and age at onset of deafness, duration of implant use, length of daily device use, and age at implantation.[7-10] As we know neural plasticity plays an important role in learning and improving cognitive abilities within 5 years of age.[11,12] So, children who did CI before 5 years can know better than later implanted children. There are a lot of tests used behaviorally to test the working memory (WM). However, it is difficult to use these tests in children.

There are two electrophysiological tests available which are used widely to evaluate the auditory WM. P300 is an event-related potential test mostly used to assess individuals' discrimination ability, cognitive ability, working memory and attentional system (Harwood V et al. 2022).[13] Essentially, the P300 response is part of an extended ALR time frame that is captured under unique stimulus circumstances. Among a group of event-related or endogenous evoked responses, P300 is one of the first auditory responses.[14] P300 is the largest positive wave, which has an amplitude between 4 and 12 μv and occurs between 300 and 500 ms. It may be bifocal, having “a” and “b” components. From early childhood, it was noted that amplitude was the only measure we could use to evaluate the P300. The amplitude and latency of the P300 component provide information about cognitive processes in the brain, such as memory, attention, concentration, and speed of mental processing in a wide range of clinical populations.[15-17]

In December 2019, it was reported that approximately 736,900 CI have been performed worldwide. (Estimates based on 22 manufacturers’ voluntary reports of registered devices to the U.S. Food and Drug Administration, December 2019).18 The results of CI vary greatly among studies, however they may be correlated with individual core auditory processing abilities. Across behavioral studies, inconsistent results have been found. Lack of sensitivity required to fully characterize the differences between subjects with varying implant ages exists in indirect audiometric tests.

Speech perception abilities can also be evaluated by auditory evoked potentials across experienced Cl users. Traditionally, click stimuli has been used to elicit P300 responses. However, owing to the limitations of clicks being broad spectrum and different from everyday listening contexts, speech stimuli has been employed by several authors to evaluate auditory discrimination abilities in children with cochlear implants.

Authors have used speech stimuli to evaluate auditory discrimination auditory processes in CI users. Age of implantation has been considered as one of the most prominent factors affecting speech perception including discrimination abilities. However, CI has been a surge in late-identified children and fundings for CI through public and private agencies. Hence, there is need to study the development of discriminative abilities in early and late implantation in children with hearing impairment.

The present study has aimed to evaluate the WM abilities and the impact of auditory deprivation in children with early vs late cochlear implantation. The objective of the study was to obtained P300 in both groups. We expected early implanted children will have a better P300 response than late cochlear implant children.

## METHODS

### *Study design*

In this study comparative experimental study design was implemented. Purposive sampling was used to collect sample. This study has been performed in the Department of Audiology, Ali Yavar Jung National Institute of Speech and Hearing Disabilities (Divyangjan), Mumbai. The study was approved by the Institutional Ethical Committee. This is a survey research design. The samples were collected by purposive sampling techniques.

### *Study period*

The duration of the study was of 11 months from January 2022 to November 2022.

### *Study population*

A total of 30 participants were included in this study, which were divided into two groups. Group 1 consisted of 15 individuals who had done cochlear implant (CI) before 3 years of age. In group 2, 15 subjects were included who had done their CI after 3 year of age and before 6 years of age.

### *Inclusion criteria*

Inclusion criteria for Group 1 include participants who have congenital non-progressive severe-profound hearing loss and received a cochlear implant before 3 years of age. They must experience 2 years of cochlear Implant. They have attended speech and language therapy at least for one year. Inclusion Criteria for Group 2 include Children with congenital non-progressive severe-profound hearing loss who had received a cochlear implant, Implanted post 3 years up to 6 years. Children having chronological age 4-8 years. Children having hearing age of at least 2 years. All the children have aided/CI assisted threshold within speech banana.

### *Instrument and materials*

*Otoscope*

An otoscope was employed to visually inspect the ear canal and tympanic membrane. This step ensured a thorough examination of the external auditory structures for any potential abnormalities.

*Resonance dual channel audiometer*

CI Assisted aided Pure tone audiometry was conducted using a Resonance Dual Channel Audiometer. This instrument allowed for precise measurement of hearing thresholds across various frequencies, providing essential data on participants' hearing acuity through CI.

*Neurosoft instrument*

The P300 test was performed using a Neurosoft instrument. This specialized equipment allowed for the measurement and analysis of P300 responses to tone burst stimuli.

*HP speaker (DHS- 2101)*

Speaker was used as transduced during acquisition of P300 using speech stimuli.

Two types of stimuli, a standard speech stimulus with consonant contrast /ba-da/ accounting for about 80% of the stimuli was presented as non-target or frequent stimuli and subject's own name accounting for about 20% of the stimuli were presented as target or infrequent or rare stimuli in the oddball paradigm at 50 dBSL. The oddball paradigm was implemented, randomly introducing uncommon stimuli. Participants were instructed to focus on the rare stimuli, forming the basis of the P300 assessment.

*Procedure*

Inform consent was taken from parents of the participants. All the procedure were explained well to the parents. Following the otoscopic examination Aided audiogram was administered using resonance audiometer.

*Pure tone audiometry*

Participant was asked wear his/her CI sound processor. Aided pure tone audiometry was conducted using a resonance R37a clinical audiometer. The evaluation took place in a sound-treated two-room setup, adhering to noise level standards within permissible limits (ANSI S3.1). Warble tone was used to estimate the free field threshold at octave frequencies ranging from 250 Hz to 8000 Hz.

*P300 test*

The P300 test was conducted in a quiet room where participants were comfortably seated. Electrode placement sites were prepared using neuoprep solution, and 10-20 conduction gel was applied to optimize electrode conductivity. Electrodes were affixed using microporous adhesive tape, with an accepted impedance of up to 5 kilo-ohms. Electrode positions included Cz for the non-inverting electrode, M1/M2 for the inverting electrode, and Fpz for the ground. Low pass filter setting was 50 Hz, high pass filter setting was kept at 0.01Hz, and the notch filter was turned off to preserve important frequencies. A total of 400 sweeps were used for data acquisition, with parameters detailed in table 1.

**Table no 1: Parameters used for P300 testing.**

| Parameters | Value |
|---|---|
| **Stimulus type** | Speech/ba-da/ (Non frequent) Name calling (Frequent) |
| **Analysis epoch** | 250-700 ms |
| **Non-meaning full tone** | 30 dB SL |
| **Rare or meaningful tone** | 30 dB SL |
| **Filters: high pass cut off** | 50 Hz |
| **Low pass cut off** | 0.1 Hz |
| **Probability of target tone** | 20% |
| **Transducer type** | Insert earphone:Er-3A |
| **Rate of stimuli** | 1.1/Sec |
| **Polarity** | Alternating |
| **Amplification** | 75000 |

*Subject instruction*

Participants were instructed that they would hear a continuous /pa-ba/ sound and sometimes you will hear your own name. Their task was to pay attention to the infrequent sound i.e., their name and press a button simultaneously or raise their hand. Trial run was carried out until the child was used to the test procedures. After the child got acquainted with the procedure, the actual test was started. The procedure was the same for each participant.

*Identification of latency and amplitude of P300*

Analysis of the P300 waveform involved an averaging process. A minimum of two tracings for both infrequent and frequent stimuli were recorded per patient to enhance reliability. Tracings were averaged, and the wave with the highest positive peak post the N1-P2-N2 complex was selected. Latency measures were determined at the center of the peak, while amplitude measures were taken at the location of the largest slope in the peak. Latency reference values ranged from 225 to 265 ms, and amplitude reference values ranged between 5 to 20 µV. Amplitude was marked from the N2-P3 waveform.

## RESULT

The data collected for the study were subjected to statistical analysis using SPSS (26 version) software. Initially, the Shapiro-Wilk test for normality was applied to assess if the data adhered to normal distribution assumptions. All the data are normally distributed hence parametric test was used to assess the data. The early implant participants' age varied from 4 to 8 years while the mean chronological age was 6.7 years. The mean hearing age stands at 4.23 years and mean implant age was 2.5 years. In the late implant participants, the mean chronological age was 7.7 years, while hearing age and implant age was 3.03 and 4.6 years respectively. In early implant group the P300 amplitude ranged between 12.5 µv to 20.6 µv (M:17.36, S.D: 2.59). The mean value of P300 latency was 301.89 msec (S.D: 39.94) while in late implant group the mean P300 amplitude was 9.53 µv (S.D:1.35). The P300 latency ranged from 306.9 msec to 509.3 msec (M:401.49, S.D:72.40).

**Table 2: Descriptive statistics of both groups.**

| | Minimum | Maximum | Mean | S.D. |
|---|---|---|---|---|
| **P300 amplitude early implanted group** | 12.5 | 20.6 | 17.36 | 2.59 |
| **P300 latency early implanted group** | 234 | 377 | 297.3 | 39.94 |
| **P300 amplitude late Implanted group** | 6.2 | 11.2 | 9.56 | 1.37 |
| **P300 latency late implanted group** | 306.9 | 509.3 | 401.49 | 72.40 |

***Comparison between two groups***

To ascertain whether there is significant difference exist in P300 amplitude and latency between these groups independent sample t test was carried out. The t test value for P300 amplitude (t:10.34, $p<0.05$) and latency (t-4.66, $p<0.05$) indicate that there are statistically significant differences exist between the two groups in terms of P300 amplitude and latency. From the mean value we can conclude that early-implanted individuals have higher amplitude and shorter latency compared to late-implanted individuals.

**Table 3: Independent sample t-test between two groups.**

| | t value | df | P value |
|---|---|---|---|
| **P300 amplitude** | 10.34 | 28 | 0.00001 |
| **P300 latency** | -4.66 | 28 | |

## DISCUSSION

P300 can be used to evaluate auditory working memory. Hearing-impaired individuals have reduced working memory capacity. In many research, it was observed that people with high working memory capacity can get maximum benefit from amplification devices or even from cochlear implants.[19,20] There are so many factors that affect the outcome of the CI. One of the most important factors among them is the age of implantation. It was noted that early implanted individuals have better speech and listening abilities. This study was implemented to ascertain whether there is a significant difference in auditory WM between early and late implanted CI.

According to the auditory scaffolding concept, the auditory sense is specifically and innately made to deal with temporal and sequential patterns. Early auditory experiences help young children understand these patterns; if these experiences are delayed, the learning of these sequential functions is delayed as well, which might produce language issues due to the reliance on sequential patterns. Hearing loss negatively affects experiencing temporal and sequential patterns of auditory information.[21,22] So children with hearing impaired failed to discriminate the sound and process the sound for which the WM also decreased. P300 is used as an event-related potential to measure individuals' phonological working memory abilities.[13] In this study, P300 was used to evaluate the phonological WM of CI children. This study found a statistically significant difference in P300 latency and amplitude between early and late implant individuals. According to Shubhadarshan A et al hearing-impaired individuals have increased latency and reduced amplitude.[23] Late CI-implanted individuals have reduced P300 amplitude and increased P300 latency.

This study is consistent with a previous study by Jayachandran D et al.[24]When they compared the latency and amplitude between early and late cochlear implanted children, it was found that there was a significant difference. However, the results from the present study contradict with the findings that are reported by Ghiselli et al.[25] They reported, upon comparing the latency and amplitude between early and late cochlear implanted children that there was no significant difference, and suggested that late cochlear implantation did not affect the outcome of P300 that's might be the different age group chosen by them.

Not only does working memory differ from person to person, but it also varies with age. Working memory begins to develop in infancy and grows quickly throughout the first year of life.[26-29] This capacity increases during childhood, reaches a plateau in mid-to-late adolescence, and drops beyond age 40–50, but not as sharply as it did during early development.[30-33] The critical period has an enormous effect on brain development. Children generally achieve and learn a maximum concept during the critical period. The WMC increases in the critical age. Early CI individuals can use the critical age maximum to train their auditory function and hence will improve the WMC.

## CONCLUSION

The results of this study have significant ramifications for how the therapeutic strategy for kids with congenital hearing loss is planned. It highlights the need of early action and the crucial timeframe. It assesses the neuromodulation of the brain's auditory regions directly and connects it to the implanted age. It emphasizes how crucial it is to take into account behavioral tests like temporal patterning and the P300 evoked potential test when evaluating cochlear-implanted children before therapy.

*Funding: No funding sources*
*Conflict of interest: None declared*
*Ethical approval: The study was approved by the Institutional Ethics Committee*

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**Cite this article as:** Puri N, Shubhadarshan A. Working memory capacity in children with early and late cochlear implantation: a P300 evaluation. Int J Otorhinolaryngol Head Neck Surg 2024;10:495-500.