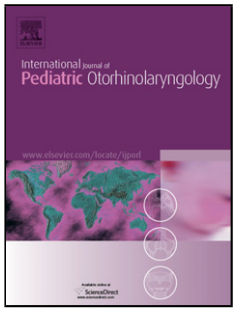

Title: An exploratory study of visual sequential processing in children with cochlear implants

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Abstract

Objective: The objective of the study was to compare visual sequential processing in school-age children with cochlear implants (CIs) and their normal-hearing (NH) peers. Visual sequential processing was examined using both behavioral and an event-related potential (ERP) measures.

Methods: Eighteen children with CIs and nineteen children who had hearing within normal limits (NH) participated in the behavioral study. Subtests from the Test of Visual Perceptual Skills and the Sensory Integration and Praxis Test were administered to all children. ERP measures were collected from five children with CI and five age-matched peers. Peak latencies (N200 and P300) and reaction times for visual sequential processing were compared in these two groups.

Results: The findings of the study revealed significant group differences in visual sequential memory and visuo-motor sequencing tasks suggesting that children with severe-profound hearing loss may have difficulties in visual sequential tasks. The study also revealed longer P300 latencies and longer reaction times for a visual sequential matching task in children with CI when compared to their NH peers suggesting slower or delayed processing of visual sequential stimuli.

Conclusions: This exploratory study involving behavioral and ERP measures showed that as a group, children with prelingual, severe-profound hearing loss who use CIs have difficulties with visual sequential processing. These findings may have implications for rehabilitation for children with hearing loss in the light of recent evidence that accurate and efficient processing of sequentially presented visual stimuli is important for language and reading outcomes.

Keywords: Cochlear implants, visual sequencing, children, ERP, electrophysiology, motor sequencing

1. Introduction

Sequential (or temporal) processing refers to processing two or more stimuli that are presented non-simultaneously [1]. Sequential processing is thought to consist of four components: (a) detection of stimuli; (b) determination of the presence of more than one stimulus (i.e. stimulus individuation); (c) determination of temporal order of non-simultaneously presented stimuli, and (d) accurate sequence matching or sequence discrimination (see Farmer & Klein, 1995 for a discussion on this topic). The fourth component is a complex task given that sequential patterns of stimuli must be processed correctly, stored and then retrieved (memory component) for matching or discrimination. Deficit in any one or more of the four components may lead to problems in sequential processing of sensory signals.

Most of the activities concerning our daily lives involve sequential processing in various modalities. Listening to speech (auditory modality), reading a newspaper (visual modality), walking or writing (motor sequencing), reading braille (tactile modality) or cooking (visual, tactile, motor) all require us to process or perform sequential acts. It is suggested that the auditory modality has an advantage in sequential processing while the visual modality is better suited for the processing of simultaneous or "big picture" information such spatial configurations [2, 3, 4]. Regardless of the modality, the ability to accurately process sequential stimuli is important for learning. Difficulties in sequential processing are correlated with deficits in reading and language skills [5, 6, 7].

1.1 Sequential (temporal) processing in individuals with hearing loss

According to the *Auditory Scaffolding Hypothesis,* deafness affects cognitive abilities such as learning, recalling and processing sequential information [8]. Sound is considered as a carrier of temporal events since it is intimately tied to timing information [7]. Sound is considered to be the primary gateway (i.e. it provides scaffolding) for processing temporal information and the loss of auditory information due to hearing loss may result in limited or lack of exposure to sequential input [8]. Consequently, early-onset hearing loss may have a negative impact on encoding, representing and reproducing sequential patterns of stimuli not only in the auditory domain but also in the non-auditory modalities [8].

The prefrontal cortex is proposed to be involved in sequential processing of thought and action. It is postulated that reduced or delayed auditory-frontal connectivity, a result of early-onset hearing loss impacts sequential processing skills across various modalities [7]. Studies have supported this view by revealing that temporal (sequential) processing of visual and tactile information is compromised in adults with prelingual or congenital deafness [9, 10]. Hemming and Brown showed that while judging whether tactile stimuli, when applied to the pointer and middle fingers by a mechanical stimulator were simultaneous or not, adults with congenital / prelingual deafness demonstrated higher temporal thresholds (i.e required a longer separation between the onset of the two tactile stimuli as measured in ms) when compared to their aged-matched controls [10]. These findings suggested that temporal processing of tactile information is compromised in adults with early hearing loss. Similarly, Hemming and Brown also showed that temporal processing of visual information is compromised in adults with prelingual or congenital deafness. In their study, adults with hearing loss judged whether two (LED) illumination onsets were simultaneous or not and their performance was compared to the normal-hearing (NH) controls. Again, adults with hearing loss demonstrated higher temporal thresholds

(i.e required a greater amount of time separating the onset of the two visual stimuli) compared to their aged-matched controls suggesting that early hearing loss might impede the ability to time visual information [10]. The difficulty in temporal processing in these individuals is considered to be due to neural inefficiency as a result of recruiting more brain regions or additional pathways to support temporal processing [11, 10].

More recently, Conway and colleagues investigated visual and tactile spatial tasks as well as motor sequencing tasks in 24 children with prelingual, profound hearing loss who use CIs and their 31 age-matched peers between the ages of 5-9 years [7]. Children with hearing loss showed similar performance on visuo-spatial and tactile perception tasks when compared to their peers. However, on the motor sequencing task (sequential finger tapping) they showed significantly poorer scores when compared to the performance of their age-matched peers, as well as to normative data. These findings suggest that there is a disturbance or delay in motor sequencing in children with CIs.

In another study Conway, Pisoni, Anaya, Karpicke and Henning evaluated visual sequential processing in 25 children with CIs and 27 children with NH between the ages of 5-10 years [12]. The task involved memorizing a sequence of four colored squares that appeared sequentially on a computer screen and then tapping on the screen to show the same pattern or sequence. The study showed that while there was individual variability in performance, as a group, children with CIs performed significantly poorer than their NH peers on the visual sequence learning task. Furthermore, the study showed that the sequence learning was negatively correlated with age of implantation and positively correlated with duration of implant use. Overall, the study lent support to the hypothesis that auditory deprivation may impact processing in the non-auditory modalities.

The findings from Conway, Pisoni, Anaya, Karpicke and Henning were supported by Bharadwaj and colleagues who also showed that children with prelingual severe-profound hearing loss who use CIs have difficulties in temporal processing of sensory stimuli [12, 13]. In their study Bharadwaj and colleagues investigated performance of children with hearing loss between the ages of 5 – 8 years 11 months on spatial (visual, tactile and proprioception) and temporal tasks (in tactile and proprioception modalities only). They found that as a group, children with CIs performed in the average or above average range on spatial tasks across all three modalities when compared to the normative data. However, they showed below average performance on temporal (sequential) tasks in the tactile and proprioception modalities. Together these studies suggest possible disturbances in motor sequencing and sequential processing of visual, tactile and proprioception stimuli in pediatric cochlear implant users.

Difficulties in sequential processing of stimuli and sequencing motor movements in children with CIs have been linked to language outcomes. For example, the performance on motor sequencing tasks in children with CIs was shown to be positively correlated with their performance on a standardized test of language skills. Similarly, disturbances in visual sequential processing in children with CIs have also been linked to poorer language abilities [7, 12]. While deficits in sequential processing of stimuli have been documented, it is not clear what aspects or components of sequential processing are affected in pediatric users of CIs. Thus it is important to not only examine whether there are disturbances in non-auditory sequential processing in children with hearing loss but also to investigate the nature of this deficit. For this reason, we used ERP (event-related potential) technique to explore the underlying mechanisms that may contribute to the deficit. ERP components highly correlate with various sensory processing parameters and can identify modulations in the latency of responses in the sub-millisecond

temporal range. The ERP part of the study was exploratory in nature and was conducted to determine if the ERP components can further inform us about visual sequential processing in children with CI.

The objective of this study was to investigate visual discrimination, visual memory, visual sequential memory and visuo-motor sequencing in children with and without hearing loss using behavioral and ERP measures. Specifically, performance on these visual tasks was evaluated in the context of the sequential processing framework proposed by Farmer and Klein [1]. Compared with behavioral procedures, ERPs provide a continuous measure of processing between the presentation of a stimulus and a response, making it possible to determine stages of processing that are being affected by a specific experimental manipulation. Hence we explore this technique to investigate various components of sequential processing proposed by Farmer and Klein in children with CIs and their NH peers [1].

2. Methods

2.1. Participants

Eighteen children with CIs and nineteen children who had hearing within normal limits (NH) participated in this study. Children with CI (10 girls and 8 boys) were between the ages of 5 years to 10 years, 8 months (mean age: 7 years and 8 months). All children spoke English as their primary language and had prelingual, bilateral, severe-profound hearing loss. Eight children used unilateral CI and ten children used bilateral implants. All children received their first implant prior to age 3 years 10 months except three of whom received their first implant between the ages of 4 to 5.5 years. These three children used hearing aids for amplification prior to implantation. Eight participants used spoken language as their primary mode of communication

while the remaining ten used speech with supported signs for communication. Children with reported history of developmental delays, vision problems, and those suspected of having, or diagnosed with, Autism Spectrum Disorders were excluded from the study. Additionally, two children with CI were excluded from participation based on their poor performance on the Non-verbal Index (NVI) of the Kaufmann Assessment Battery for Children- 2nd Edition [14].

Children with NH (11 girls and 8 boys) were between the ages of 6 years, 3 months to 12 years; 1 month (mean age: 8 years and 4 months). Based on the case history none of them had a history of developmental delays, speech, language or hearing problems. All participants received an honorarium for their participation.

[Insert table 1 here]

2.2 Procedures

Data collection complied with the Institutional Review Board at the Office of Research and Sponsored programs at Texas Woman's University. All parents completed a case history form pertaining to developmental, speech, language, hearing, medical and social history. Following the consent, testing was carried out on two separate days that lasted approximately an hour each. Behavioral measures were collected during the first session and ERP measures were collected during the second session.

2.2.1 Behavioral measures

Subtests from two different standardized and norm referenced instruments were administered to all children. From the Test of Visual Perceptual Skill, the following three subtests were administered: Visual Discrimination, Visual Memory, and Visual Sequential

Memory [15]. All three subtests yielded scaled scores (Mean =10 and *SD* =3) and are described as follows.

a. *Visual Discrimination task*: For this task, the child is shown a stimulus at the top of the page, and is asked to select which of the four shapes at the bottom of the same page matches the stimulus.

b. *Visual Memory task:* For this task, the child is first shown a figure for 5 seconds. When the page is turned, the child has to select from 4 figures the one that matches the previously seen stimulus. Thus this subtest evaluates short-term memory for visual symbols.

c. *Visual Sequential Memory task:* For this task, the child is shown a pattern of shapes for 5 seconds. These shapes are not temporally separated. When the page is turned the child has to select from four choices which pattern of shapes matches the previously seen stimulus. The number of shapes in the sequence increase from 2 to 8 as the difficulty level increases. Thus this subtest assesses the child's ability to recognize a series or pattern of shapes, hold that pattern in memory and match it with the exact pattern when provided four choices. This subtest also evaluates short-term memory for a progressively longer sequence of visual symbols and the ability to distinguish between two sequences.

One subtest, Sequential Praxis, from the Sensory Integration and Praxis Test was administered to all children. This subtest yielded z scores (Mean 0 and *SD* =1) [16].

d. Sequential Praxis subtest: This subtest assesses a child's ability to execute a series of hand or finger movements demonstrated by the examiner. The hand movements generally involve tapping on the table, along with the other hand or the head in a specified position and in a specified sequence. Although this task involves motor sequencing, it also relies on visual

interpretation and memory. This subtest is referred to as visual-motor sequencing in the rest of the paper.

All of the above tests were administered by a licensed Pediatric Occupational Therapist. All children were tested individually and the instructions were delivered verbally to all of them since none of them showed difficulty understanding spoken language. Administering practice items helped ensure that participants understood the tasks. The scaled scores and *z* scores obtained from the subtests were used in statistical analyses.

2.2.2 Event-Related Potential (ERP) Measure

An ERP is the measured brain response that is the direct result of a specific sensory, cognitive, or motor event [17]. More formally, it is any stereotyped electrophysiological response to a stimulus which can provide a noninvasive means of evaluating the neural temporal framework of sensory, cognitive and/or motor events. Event-related potentials recorded by scalp electrodes have long been studied and have demonstrated sensitivity to sequential processing of various types of stimuli [18, 19]. ERPs are derived from portions of electroencephalographic (EEG) activity that are time-locked to specific events. The ERP waveform consists of a series of positive and negative voltage deflections or components in an electroencephalographic (EEG) brain activity for a sensory event. Traditionally, the nomenclature used to describe each component reflects its polarity, either positive or negative.

In the present study, ERP components involved in visual sequential processing were examined in a small number of children with CI and their NH peers. This part of the study was exploratory in nature and was designed to evaluate the temporal trajectory of visual sequential processing. The component waveform of interest (see figure 1) is the negative component

peaking around 200 ms or N2 indicative of stimulus detection and visual processing [20, 21]. This negativity is typically followed by a positive component peaking between 300 to 600 ms referred to as P3 which is indicative of the processes involved in stimulus evaluation, context updating and working memory [22, 23]. Verleger suggests that P3 is highly sensitive to structured tasks as participants associate and evaluate various elements of pattern recognition and sequencing [24]. To our knowledge no single study has investigated ERP correlates of visual sequential processing in children with CI.

[Insert Figure 1 here]

2.2.2.1 Participants

Two groups of children participated in this study: five children with CI and five age-matched typically-developing, NH children. A subset of children with CI who participated in the behavioral study (Participants: CI07, CI08, CI09, CI10 and CI13) took part in the ERP study. Children with CI (2 boys and 3 girls) were between the ages of 8 and 12 years. The NH children (2 boys and 3 girls) were between the ages of 8 and 11 years. As per parental reports, there were no indications of any history of a hearing loss, speech impairment, or cognitive delays in NH children. All children received an honorarium for their participation.

2.2.2.3 Stimuli

The stimuli consisted of visually presented line drawings of geometric shapes developed to match those used in the Visual Sequential Memory subtest of the TPVS instrument that was administered in the behavioral study. A total of eight different shapes (circle, square, star, triangle, cross, heart, diamond, rectangle) in the form of black line drawings on white background measuring 2 X 2 inches were used. The shapes were developed on MS Power Point

and presented via Stim 2 software of Neuroscan electrophysiological data presentation system [25]. The target stimuli consisting of a sequence of any three shapes were presented to the participants on 50" TV screen placed directly in front of the participant at a distance of 2.2 meters.

2.2.2.4 Experimental Task

The experimental task was a variation of a 'priming' task. In a typical behavioral priming experiment, the participant is presented with a sequence of two words. The first word is called the 'prime', and the second word the 'target'. The participant is instructed to make a predetermined, appropriate response to the target word. For example, in a matching experiment the instruction might be to press one button if the target matches the category of the prime, and to press another button if the target is not a member of that category. In the current study, the task was a variant of a priming paradigm in the visual modality. Each trial included participants watching two slides with sequentially appearing visual stimuli. Slide 1 included sequential presentation of three shapes in one row (S) - the prime. This was followed by presentation of slide 2 that included presentation of three shapes in two rows (R1 and R2) - the targets. Each target slide (S2) had one row of target that matched the prime and one row of unmatched target. Participants were asked to determine whether 'S' matched 'R1' or 'R2' (see Figure 2). An inter-stimulus interval (ISI) of 3000 ms separated S from R1 and R2. An inter-trial interval (ITI) of 5s was interposed between the end of one trial and the beginning of the next to allow for a response from the participants. The matched and unmatched rows were randomized and counterbalanced so that there were equal numbers of matched and unmatched targets in each row across the trials.

[Insert Figure 2]

Each participant was asked to watch all the three sequences of S, R1 & R2 before responding to whether S matched either R1 or R2. A pad with two buttons, one button for the 'R1' response and one for the 'R2' response, was provided with the buttons placed side-by-side and separated by a distance of 1.2 inches. The participants were instructed to use only the index finger of the right hand to respond by pressing one of the buttons. Practice trials were provided until each participant successfully completed practice trials and stated that they understood the task. Participants completed a total of 200 trials consisting of 10 blocks of 20 trials each. Rest breaks were provided at the end of a block when needed. The experimental session took approximately 30 minutes. Behavioral and ERP data were collected from each of the participant.

2.2.2.5 ERP Recording

EEG was simultaneously recorded from 30 silver-silver chloride electrodes mounted in an elastic cap and affixed to the scalp according to a modification of the International 10-20 system via Neuroscan electrophysiological data acquisition system [25]. All electrode impedances remained below 15 kΩ. Two electrodes placed above and at the outer canthus of the left eye monitored eye movement and blinks. EEG channels were referenced to linked mastoid electrodes with Fpz as ground. Ongoing EEG activity was sampled at 1000 Hz, amplified, analog-filtered from 0.15 to 70 Hz, digitized, and stored for later off-line analysis

2.2.2.6 Data Analyses

Off-line, individual epochs, encompassing –200 to 1000 msec relative to stimulus onset, were derived for each participant. Epochs were rejected if any activity (artifacts) in the eye channel exceeded +/- 50 microvolts. Following artifact rejection, epochs were separately

averaged, linearly detrended and digitally low-passed filtered at 20 Hz (using a filter slope of 48 dB/octave) and grand averaged for each condition of S, R1 and R2 for each group. Difference between the mean amplitudes of grand averaged waveforms between matched and unmatched target stimuli over the latency range of 150 – 650 msec for both NH and CI groups was computed. Further, topographic maps of the obtained waveforms for each condition were also generated by Scan 4.2 Edit software by interpolating the voltages between adjacent electrodes. These were visually inspected to determine areas of maximal activity which was over the parietal array of electrodes. The maximal activity was seen at PZ electrode. To quantify specific aspects of ERP components, temporal windows were set to bracket the ERP component of interest, N2 and P3, across all of the individual subject's waveforms. Hence, the highest negative amplitude between 150 to 250 msec was selected for N2 and the highest positive amplitude between 300 to 450 msec was selected for P3. The obtained data points were statistically analyzed using a repeated measures ANOVA design using StatView [26]. Group affiliation served as the between-subjects factor. Statistical significance was evaluated at the 0.05 alpha error level. The measures of interest included: N2 latency, P3 latency, accuracy data and reaction times.

3. Results

3.1 Behavioral measures

Nonparametric Mann–Whitney *U* tests were conducted to examine differences between the two groups (i.e. cochlear implant & NH) on the four subtests. Figures 3-6 show group differences between children with CI and children with NH for various visual tasks and visuo-motor sequencing task in terms of boxplots. The ends of the whiskers represent the maximum and minimum values, the ends of the box show first and the third quartile and the line in the

middle of the box represents the median. Figures 3 and 4, show performance of children with CI and children NH on Visual Discrimination and Visual Memory subtests. Analyses did not reveal significant group differences on these two tasks.

[Insert figures 3 and 4]

As shown in Figure 5, results revealed a significant difference between groups for the Visual Sequential Memory subtest, $U = 115.0$, $p = .08$. Scores were significantly higher for the NH group ($M = 10.84$, $SD = 2.3$) compared to the CI group ($M = 8.71$, $SD = 3.13$).

Similarly, a significant group difference was found for the visuo-motor sequencing subtest as shown in Figure 6 ($U = 89.5$, $p = .03$). Scores were significantly higher for the NH group ($M = .39$, $SD = .92$) compared to the CI group ($M = -.42$, $SD = 1.23$).

[Insert figures 5 and 6 here]

Overall, the findings suggest that the performance of children with CIs on both the visual sequential memory and the visuo-motor sequencing tasks was relatively poorer compared to their NH peers. There are no standardized tests that incorporate non-simultaneous (temporally separated) symbols to assess visual sequential processing. Therefore, a visual sequential task was created based on the visual sequential memory subtest of the TPVS where the visual symbols appeared sequentially.

3.2 ERP measures

Although data were collected from all 30 channels, the main focus of analyses was on the parietal electrodes (P-array) as the scalp activity was most robust across the P-array of electrodes (P7, P3, PZ, P4 & P8) especially at PZ. Quantification of peak latencies allows for determining

when a component shows significant temporal difference between experimental conditions of interest [27]. By visually determining at what point, each component, reaches its maximum amplitude peak, the results can provide information about the speed and timing of the cognitive process. In this study, the conditions of interest were the participants' responses to stimuli (S) as either R1 or R2 and the waveform component of interest were N2 and P3. Waveforms generated to R1 and R2 responses were grand-averaged and further analyzed for both groups.

Comparisons of grand-averaged matched and unmatched target waveforms showed no significant differences between them and hence the waveforms were collapsed and comparisons were made to analyze group differences. Figure 7 shows grand-averaged waveforms for the two groups at electrode PZ. Analyses of peak latencies of N2 revealed that the differences between the groups were marginal $F(1,8)=2.79$, $p=0.06$. Analyses of peak latencies of P3 component revealed an overall main effect of group, $F(1,8)=10.15$, $p=0.01$. The CI group was significantly slower in the evaluation of visual sequential stimuli when compared to the NH group as seen from figure 8. This result was further corroborated by the analyses of reaction times (behavioral data) that also showed significant differences between the CI and NH group $F(1,4) = 7.33$, $p = 0.05$ as seen in figure 9. No difference in overall accuracy was observed between the two groups $F(1, 4) = 1.01$, $p = 0.37$.

[Insert figures 7, 8, 9 here]

4. Discussion

The present study investigated sequential processing in children with CIs and their NH peers using behavioral and ERP measures. For behavioral measures, group comparisons were

made specific to visual discrimination, visual short-term memory, visual sequence discrimination, and imitation of finger/forearm sequential movements. First, children with CIs showed similar performance on visual discrimination and visual memory tasks when compared to their NH peers. These findings support the view that children with CIs show average or above average performance on visual spatial tasks [7, 13]. Previous studies have also shown that children with CIs indeed have strengths in the areas of visual memory and visual working memory and perform as well as or better than their NH peers on these tasks [28, 29, 30]. Second, the findings revealed that children with CIs performed significantly poorly when compared to their NH peers on the motor sequencing task, supporting the findings of Conway and colleagues [7]. Third, the visual sequential memory task also revealed a group difference suggesting that children with Cis also have difficulties with this task when compared to their peers. This finding is in contrast to findings of some of the earlier studies. As mentioned previously, many earlier studies have revealed strengths in visual memory and visual working memory in children with CIs. The visual sequential memory task used in the present study required memorization of the sequence of 2-8 symbols and matching it with one of the two provided choices. Depending on the number of stimuli in the sequence, this task required a child to hold a progressively longer chunk of simultaneously presented visual symbols in the buffer while evaluating which of the two choices match that sequence. The differences in the findings of this study compared to previous studies could be due to differences in the task complexity. Nevertheless, the findings might point to difficulties in holding a larger chunk of visual sequential stimuli.

Upon examination of individual data, seven of the 18 children with CIs demonstrated below average scores on the visual sequential memory task when compared to normative data.

Five of these children also demonstrated below average performance on the visuo-motor sequencing task when compared to normative data. The individual variability might reflect the heterogeneity present in the group of children with CI who participated in this study. While most of the children used an oral mode of communication, some used sign-supported speech. Also, half of the children with CIs had unilateral implant while the other half used bilateral implants. These factors along with the age of implantation and duration of implant use may have contributed to the individual variability seen in this study. Overall, the behavioral measures indicated that visual sequential memory and visuo-motor sequencing is significantly poorer in children with CIs compared to their NH peers. What aspect of the sequencing task is difficult for children with CI? This question was examined using the ERP measures.

ERP measures were collected from five children with CI and their age-matched peers to examine the possible temporal trajectory for visual sequence processing from the perspective of Farmer and Klein model [1]. The task was a variation of a visual priming paradigm that allowed comparison of waveforms elicited by the target stimuli from NH and CI groups. The primary advantage of the ERP design was the simplicity of the task and ease of understanding that made it amenable to use with children. The ERP measures collected from children with CI and their NH peers included N2 latency, P3 latency, reaction times and accuracy. A P3 – ERP component is considered to be an index of target detection and evaluation and the results from the analyses of the P3 component suggested that evaluating visual sequential stimuli is significantly slower in children with CI. Although data did not reach significance for the N2 - ERP component, differences between CI and NH groups were evident in this component as well, indicating that stimulus detection and visual sequence processing is possibly delayed in children with CI. It must be noted here that a lack of statistical significance could be attributed to the small sample

size of participants in the study. Also, it is a well-established fact that waveform components are often influenced by subsequent large negativity or positivity [27]. In this case, N2 appears to be influenced by the subsequent positivity of P3. A larger sample size could possibly reveal significant differences between groups in the N2 component as well. The clear differences in the P3 component between the two groups, suggest that children with early-onset hearing loss appear to take longer to accurately discriminate temporal sequences. Further, the behavioral responses in terms of reaction times corroborate the ERP results in that children with CI indeed take longer to evaluate the visual stimuli when compared to their NH peers. There is evidence that lack or delays in development of temporal processing skills in one modality may influence its development in other modalities [8, 31, 32, 33, 34]. The premise of these studies appears to be that integration of information from different senses is essential to development of normal function of each sensory system and that delays in one may create associated disruption in others as well. Harris & Kamke demonstrated that early auditory deprivation may have impact on attentional factors, especially attention to visual details in children with CI [35]. The authors suggest that children with CI may rely more heavily on visual input than do their NH peers. Children with CI appear to attend to visual information but may process it differently, than their NH peers, and that may give rise to slower overall responses. The ERP data in the present study appears to corroborate such evidence. Even though children with CI displayed sequential processing ability (there was no significant difference in the accuracy between the two groups), their performance did not reach that of the NH controls (as specified by delayed reaction times and P3 latency measure). Auditory deprivation during formative years appears to impact the visual system in children with CI. The delays in processing and evaluation of visual sequential information may have considerable impact on language and reading skills [6, 12].

5. Conclusion

The current study revealed difficulties in visual sequential memory and visuo-motor sequencing in school-aged children with CIs compared to their NH peers. The ERP measures supported the behavioral measures in addition to providing some insights into the temporal trajectory of visual sequential processing. In the current study, stimulus detection and discrimination do not appear to be impacted in children with CI as there were no group differences in the accuracy of response to matching visual sequential stimuli [1]. On the other hand, sequence discrimination or evaluation as indexed by P3-ERP component appears to be delayed in children with CI.

While the sample size was very small, it is possible that the significant group differences in visual sequencing tasks (behavioral and ERP measures) indicate underlying neural differences between the CI and NH groups. Future studies should examine the role of age of implantation, duration of implant use, and the mode of communication on visual sequencing skills in children with CI. Further research is mandated in this area with a larger sample size and wider age ranges to not only confirm these findings but also to determine whether or not neural differences in children with CI mitigate over time with appropriate auditory experiences and intervention.

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36.

Figure Captions

Figure 1: Illustration of an ERP waveform. The components of interest are N2 elicited around 200 ms and P3 elicited between 300 to 600 ms after presentation of a visual stimulus.

Figure 2: Stimuli for the ERP study. Slide 1 shows the initial sequence of shapes (prime) and Slide 2 represents the two answer choices (targets).

Figure 3: Boxplots showing scaled scores for Visual discrimination subtest for children with cochlear implants (*n*=18) and their normal-hearing peers (*n*=19). The box plot represents the following parameters: minimum, maximum, median, 1st and the 3rd quartile.

Figure 4: Boxplots showing scaled scores for visual memory task for children with cochlear implants (*n*=18) and their normal-hearing peers (*n*=19). The box plot represents the following parameters: minimum, maximum, median, 1st and the 3rd quartile.

Figure 5: Boxplots showing scaled scores for Visual sequential memory subtest for children with cochlear implants (*n*=18) and their normal-hearing peers (*n*=19). The box plot represents the following parameters: minimum, maximum, median, 1st and the 3rd quartile.

Figure 6: Boxplots showing Z scores for visuo-motor sequencing task for children with cochlear implants (*n*=18) and their normal-hearing peers (*n*=19). The box plot represents the following parameters: minimum, maximum, median, 1st and the 3rd quartile.

Figure 7: Grand-averaged waveforms at electrode PZ showing P3 latency for matching visual sequential stimuli for both CI (*n*=5) and NH (*n*=5) groups.

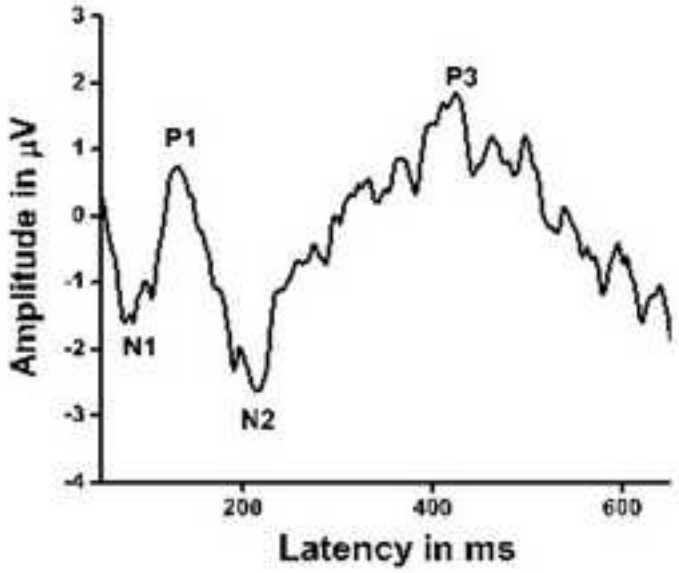
Figure 8: P3 latency measures for NH (*n*=5) and CI (*n*=5) groups for visual sequence processing. Error bars indicate standard error of mean.

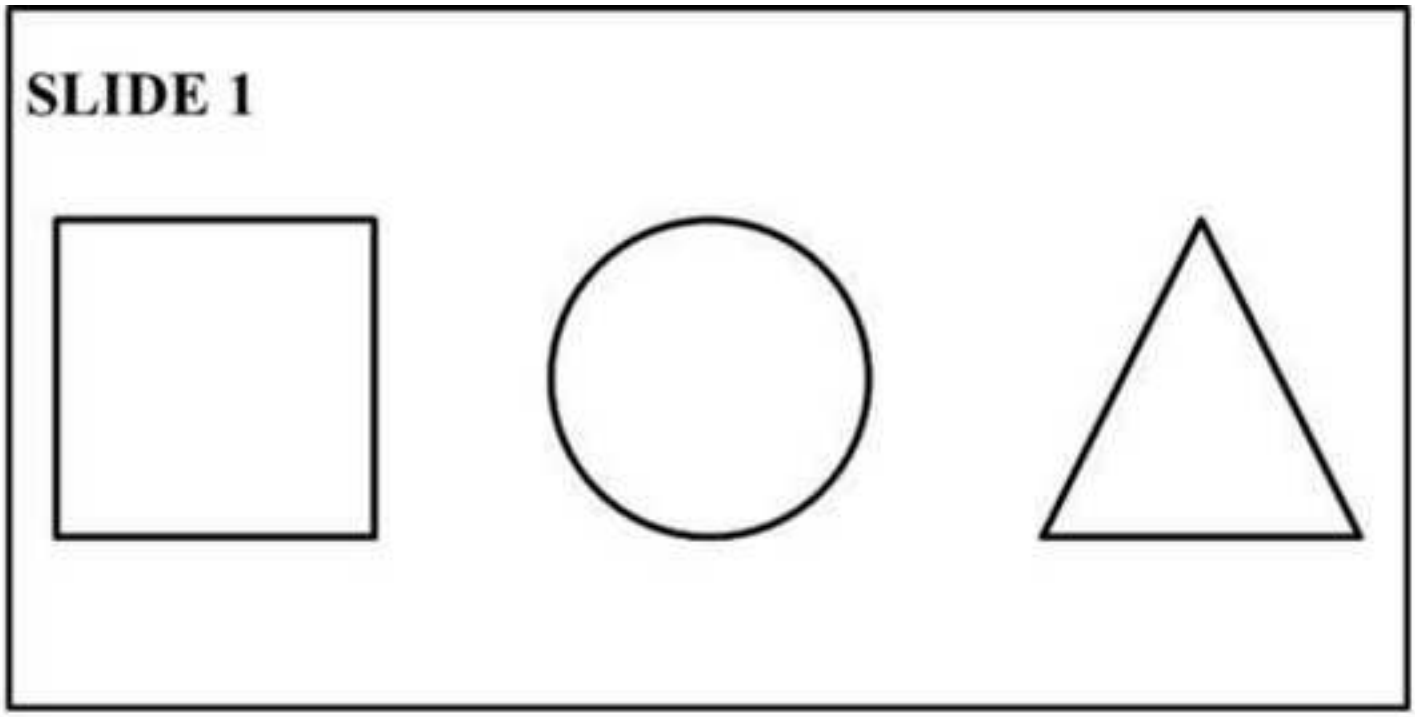
Figure 9: Differences in reaction times for NH (*n*=5) and CI (*n*=5) groups for visual sequence processing. Error bars indicate standard error of mean.

Participant	Age	Gender	Hearing Loss Type	Age at Implantation	Cochlear Implant Type	Communication Mode
C01	6 yrs; 4 mos	F	Prelingual	2 yrs 3 mos	Bilateral Nucleus Freedom	Oral
C02	7 yrs; 6 mos	F	Prelingual	5 yrs	Unilateral	Oral
C03	7 yrs; 3 mos	F	Congenital	6 mos	Unilateral	Oral
C04	6 yrs; 10 mos	M	Congenital	2yrs 2 mos	Unilateral Nucleus Freedom	Oral with sign support
C05	9 yrs; 3 mos	M	Prelingual	NA	NA	Oral with sign support
C06	6 yrs; 9 mos	M	Prelingual	3 yrs	Unilateral	Oral with sign support
C07*	8 yrs; 9 mos	F	Congenital	13 mos	Unilateral Med El	Oral
C08*	7 yrs ;7mos	F	Prelingual	3 yrs 10 mos	Bilateral Nucleus Freedom	Oral with sign support
C09*	7 yrs;11 mos	M	Congenital	1 yr 2 mos	Bilateral Nucleus Freedom	Oral with sign support
C10*	5 yrs; 0 mos	M	Congenital	1 yr 2 mos	Bilateral Nucleus Freedom	Oral with sign support
C11	5 yrs; 8 mos	M	Congenital	5yrs 6 mos	Unilateral	Oral with sign support
C12	9 yrs; 2 mos	F	Prelingual	22 mos	Unilateral	Oral
C13*	9 yrs; 7 mos	F	Prelingual	4 yrs 8 mos	Bilateral Nucleus Freedom	Oral
C14	5 yrs; 3 mos	F	NA	3 yrs 6 mos	Bilateral Nucleus Freedom	Oral with sign support
C15	7 yrs; 10 mos	F	Prelingual	2 yrs 6 mos	Unilateral Nucleus	Oral
C16	7yrs; 11 mos	M	Prelingual	1 yr 10 mos	Bilateral Nucleus	Oral
C17	10 yrs; 6 mos	M	Prelingual	3 yrs	Bilateral Med El	Oral with sign support
C18	10 yrs; 7 mos	F	Congenital	12 mos	Unilateral Med El	Oral with sign support

Table 1: Participant Demographics. * Children who participated in the ERP study

Figure 1





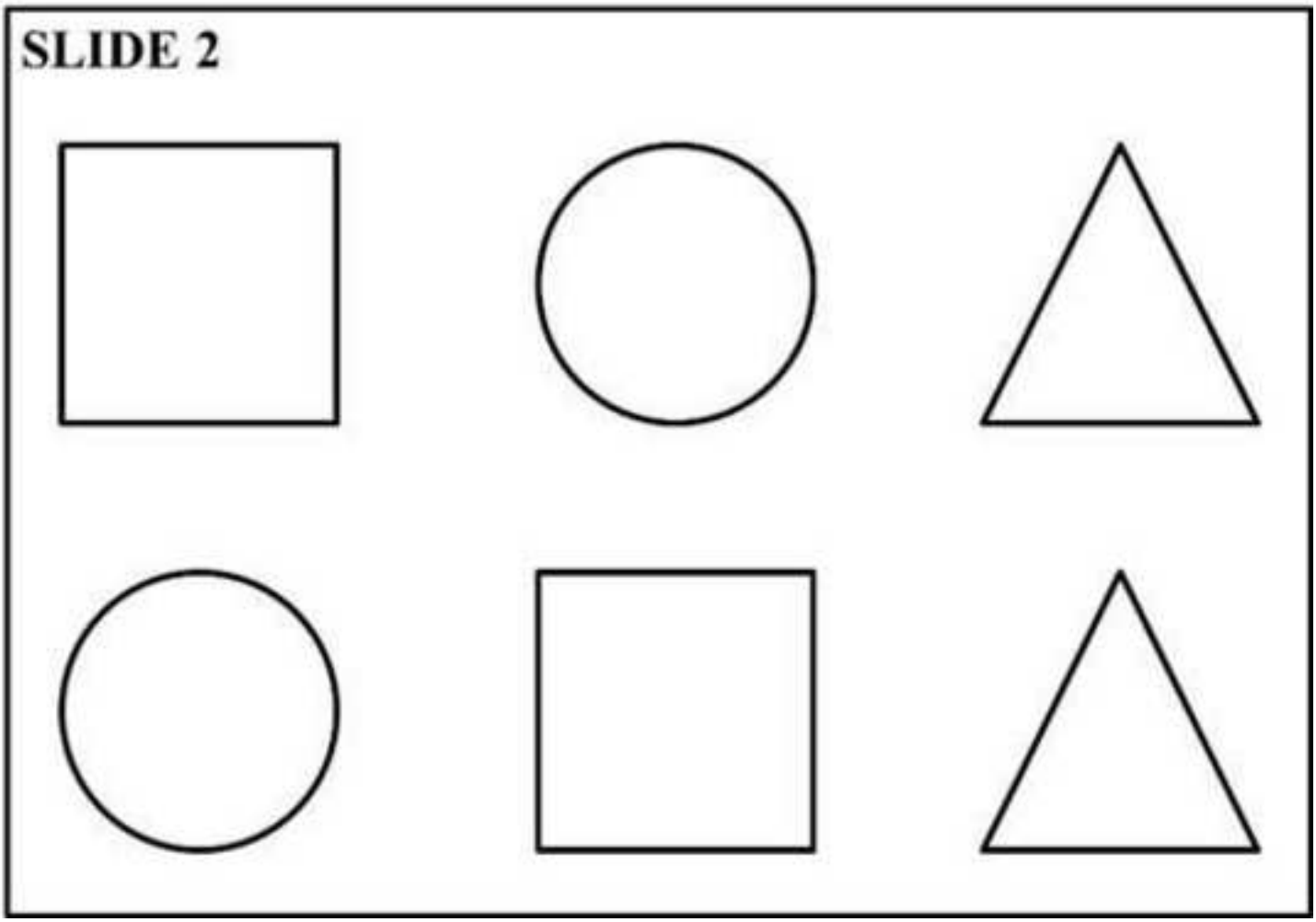


Figure 3

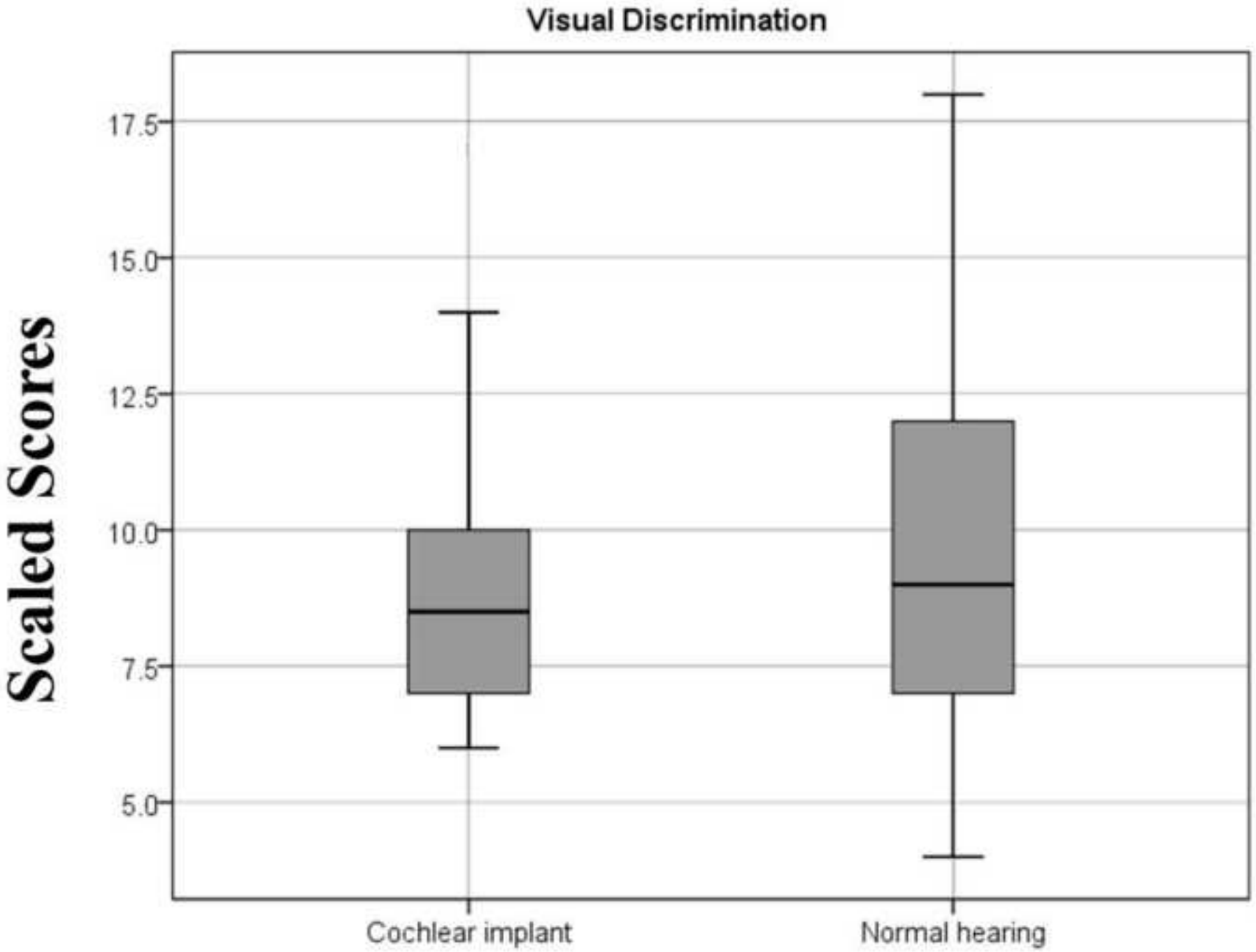

Visual Discrimination
Scaled Scores
17.5
15.0
12.5
10.0
7.5
5.0
Cochlear implant
Normal hearing

Figure 4

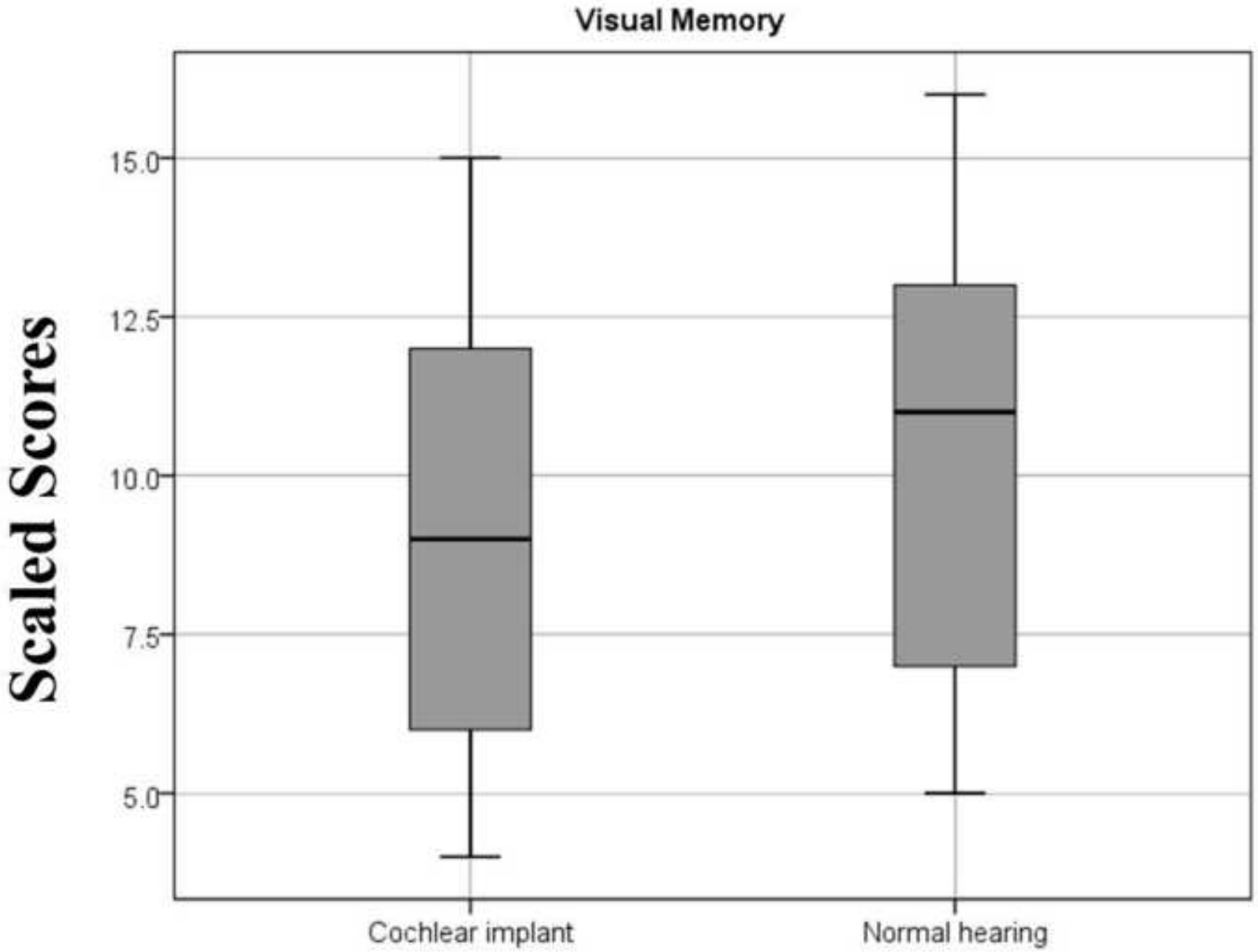

Visual Memory
Scaled Scores
15.0
12.5
10.0
7.5
5.0
Cochlear implant
Normal hearing

Figure 5

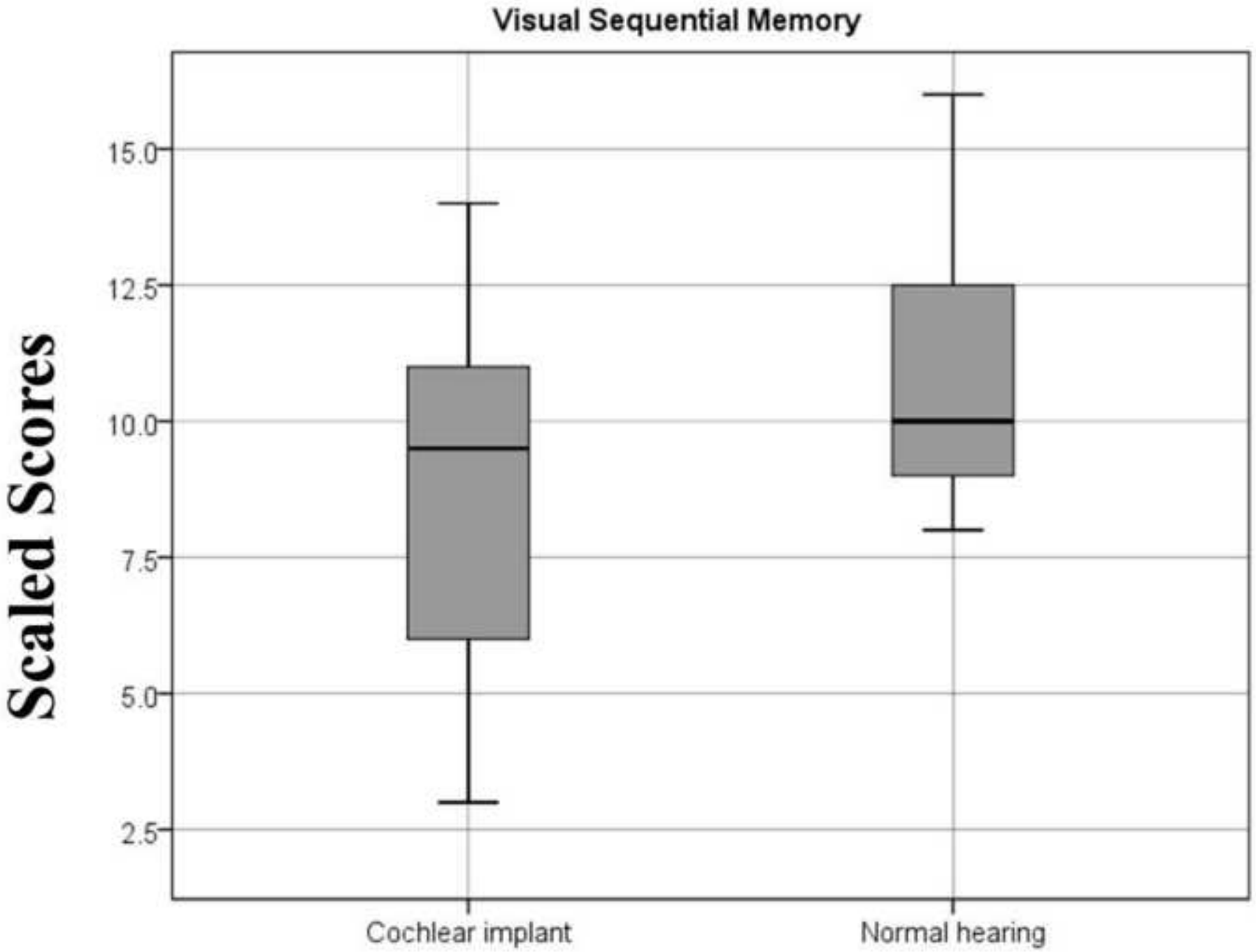

Visual Sequential Memory
Scaled Scores
15.0
12.5
10.0
7.5
5.0
2.5
Cochlear implant
Normal hearing

Figure 6

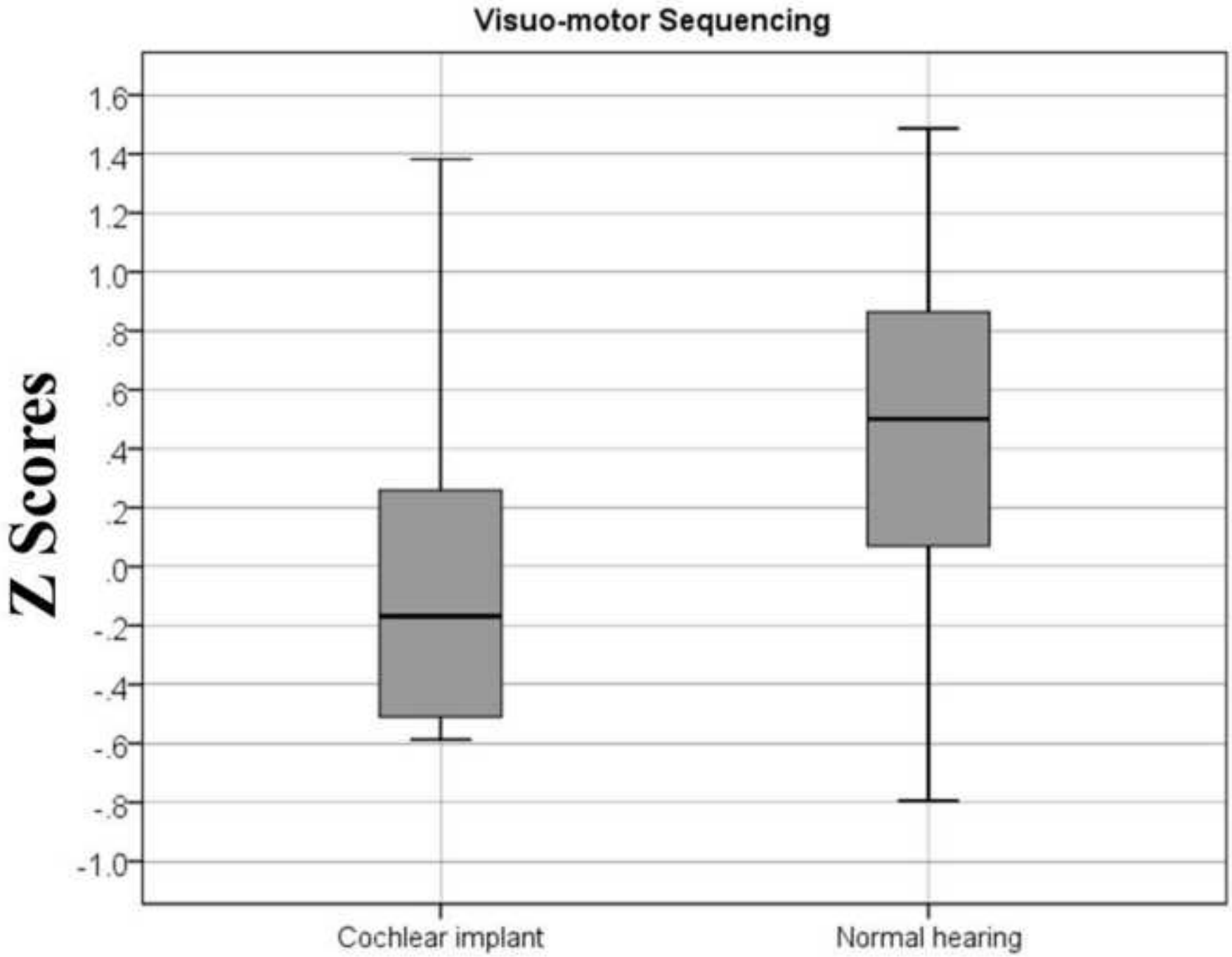

Visuo-motor Sequencing
Z Scores
1.6
1.4
1.2
1.0
.8
.6
.4
.2
.0
-.2
-.4
-.6
-.8
-1.0
Cochlear implant
Normal hearing

Figure 7

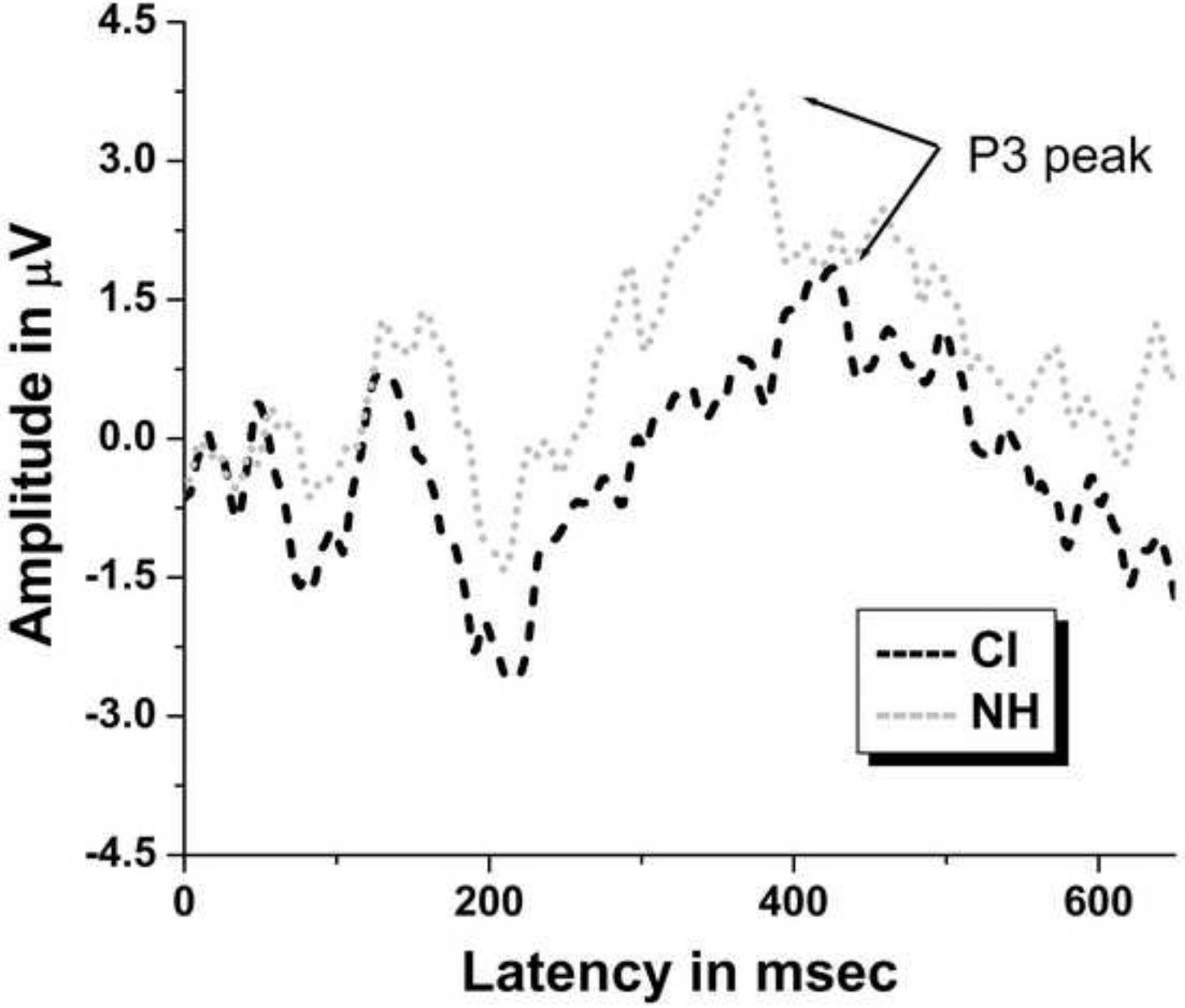

4.5
3.0
1.5
0.0
-1.5
-3.0
-4.5
Amplitude in μV
0
200
400
600
Latency in msec
P3 peak
CI
NH

Figure 8

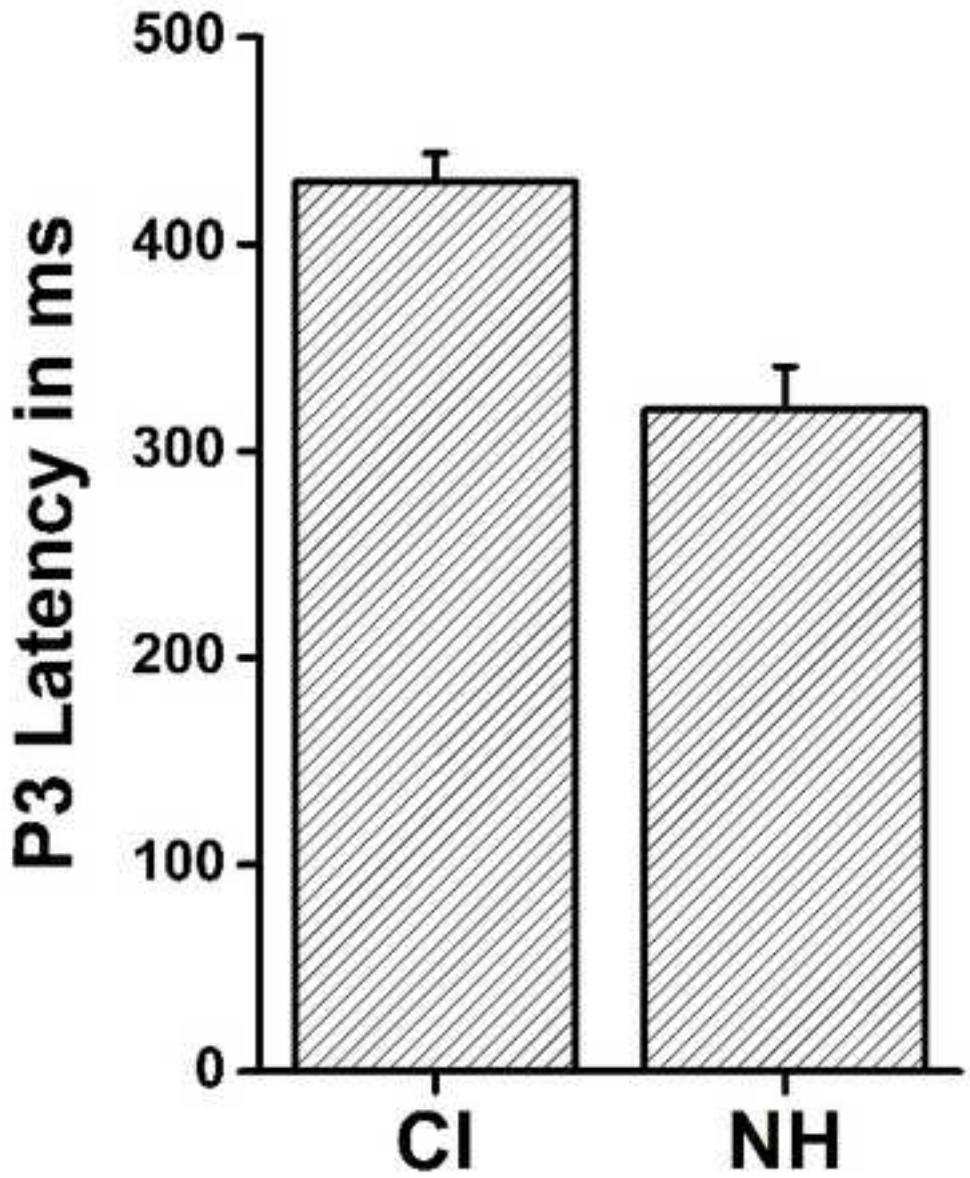


Figure 9