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Research Article

Measuring Cross Modal Plasticity Using Visual Evoked Potentials (VEP) in Children with Cochlear Implant

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Abstract

Introduction: The individuals deprived of auditory input can compensate with superior specific abilities in the remaining sensory modalities, in children with short or longer duration of deafness. Auditory cortex can be recruited by other modalities especially visual ortactile function. When subjects receive a newsensory stimulation from Cochlear Implant, the cortex undergoes re-reorganization. Visual evoked potential (VEP) is anelectrophysiological measure that can be used to measure the visual -auditory reorganization in the hearing-impaired population.

Aim: To investigate the extend of cross-modal plasticity in children with CI and to profile the morphology of VEP in subjects with varyingduration of deafness followed by CochlearImplantation.

Method: Forty-five children with Cochlear Implant between the age range of four to ten years of age. All subjects received Cochlear Implant, with minimum duration of implantation 0-1 year. Stimulus used was checkerboard pattern reversal, recorded using Allengers Scorpio EMG EO NCS system. Latency of P100and amplitude of P100 was recorded from Oz, Cz, T5 and T6 was analyzed and compared inthe implant age group, and in group with increasing duration of deafness.

Result: In this study, there was a change in the amplitude and latency of P100 across thesubjects, grouped based on the implant age, the changes were observed in all the recording sites across the groups. The amplitude of P100 was more reduced as the implant age increases, whenthe data was re-analyzed with respect to the duration of deafness, the amplitude of P100 decreased as the duration of deafness increased. The P2 component was not observed.

Conclusion: The finding suggests the visual processing skills tend to improve as a consequence of electrical input to the auditory cortex via cochlear implant in subjects with longer duration of deafness, as a result of long- term alteration of auditory experience. After implantation, as the auditory cortex of a congenitally deafened individual not only responds for the auditory stimuli, but also for thevisual stimuli. In subjects with longer deprivation of hearing the cross-modal changes of the deaf auditory cortex might hinder its recruitment by the cochlear implant input, if this cortical structure has been functionally re- organized by the spared sensory modalities. As aconsequence of this phenomenon, input from thecochlear implant may hinder in the perception ofvisual cues for speech reading skills of the subject.

Keywords: Plasticity; Visual Evoked Potentials (VEP);

The term plasticity to the neurosciences was introduced by James (1890) in The Principles of Psychology in reference to the vulnerability of human behavior to modification which is one of the prominent features of central nervous system and it denotes several capacities including adapting to changes in the environment and to store information in the memory associated with learning. Adaptation of a response to an adjacent alternative sensory modality in these sensory – specific cortices is cross modal neural plasticity; it is also the modifications and learning happening after the damage to the nervous system as a result of sensory deprivation after a prolonged absence of a sensory modality. Behaviorally, cross-modal reorganization is relevant, it is also proven by several studies using functional magnetic resonance imaging studies; investigated plasticity in the auditory cortex of deaf individuals [3]. Presently, studies found that, by providing auditory stimulation from a cochlear implant (CI), the profound deafness can be reversed [4]. Profound hearing loss usually cannot be cured, but cochlear implants can restore hearing in affected individuals. Cochlear-implants transform acoustic signals into pulses of electrical current which directly stimulates the auditory nerve. Following implantation, cochlear-implant users need time to adapt to the artificial signal produced by the cochlear-implant. Many EEG studies suggests that this variability is related to reorganization within the auditory cortex. The residual reorganization of the auditory cortex is the reason for the visual activation in the auditory cortex of cochlear-implant users. cortical reorganization induced by sensory deprivation may not completely disappear after implantation, probably because the capacity for cortical reorganization is limited [7]. Accordingly, an incomplete reversal of the deafness-induced cortical reorganization is shown in the visual activation of the auditory cortex. A visual take-over type of reorganization is manifested in the auditory cortex of cochlear-implant users. This cortical reorganization appears to be maladaptive, as it may limit the capacity of the auditory cortex to adapt to the input supplied by the cochlear implant [13]. The benefits of CI vary in all the children depending on the rehabilitation, socioeconomic status, age of deafness, duration of deafness and age of implantation [10]. To measure the functional integrity of the visual pathways from retina via the optic nerves to the visual cortex of the brain VEPs are used predominantly. In the background EEG recorded from the occipital scalp following a flash of light a VEP can often be seen extracted by Signal averaging VEP can be affected by any abnormality that affects visual cortex in the brain or the visual pathways. The VEP nomenclature is determined by using capital letters stating whether the peak is positive (P) or negative (N) followed by a number which indicates the average peak latency for that particular wave The average amplitude for VEP waves usually falls between 5 and 10 microvolts. VEPs change rapidly in form and complexity in the first six months. The changes that take place into adolescence have subtle effects on the VEP. Retinal development, cortical cell density, myelination and visual acuity are close enough to that of an adult by age 5 years, that children by this age produce adult VEP waveforms. Visual system function can be quantified by VEPs. Dysfunction can be indicated by abnormal VEPs. The early phase of the P1 component with a peak around 95-110msec, is likely generated in dorsal extra striate cortex of the middle occipital gyrus. The later negative component N2 (N150) is generated from several areas including a deep source in the parietal lobe. According to a study by Renu Yadav [33] on normal hearing children aged, 6 months to 4 years of age, they concluded that pattern reversal VEP confirmed age related reduction in latency, and increase in amplitude. Congenital auditory deprivation leads to deficits in the auditory cortex and the study indicated that the auditory deprivation led to the decoupling of the primary auditory cortex from cognitive modulation of the higher auditory areas high undergo strong cross modal reorganization [2]. The optimal time to implant a congenitally deaf child is the first 3.5 years of life when the central auditory pathways are maximally plastic, and before 7 years of age when the plasticity of the auditory pathway is reduced [5]. Functional neuroimaging studies suggests that the auditory cortex can become more responsive to visual and somatosensory stimulation following deafness, and that this occurs predominately in the right hemisphere. Using fNIRS these results confirm that auditory deprivation is associated with cross-modal plasticity of visual inputs to auditory cortex [33]. Cochlear implant users show higher auditory-evoked activations in visual cortex and higher visual- evoked activation in auditory cortex compared to normal hearing controls, reflecting the functional reorganization of both visual and auditory modalities [12]. The largest waveform was observed in the occipital cortex, where latencies were the shortest compared to both temporal cortexes and that the they had larger amplitude in the right temporal cortex [8]. They also said that if the auditory circuit between the cochlea and the auditory cortex was not successfully restored, visual- auditory cross-modal plasticity in and around auditory cortex could remain, causing negative performance after cochlear implant. The aim of the study was to investigate the extend of cross-modal plasticity in children with CI and to profile the morphology of VEP in subjects with varying duration of deafness followed by Cochlear Implantation.

Patients and Methods

Patients

The study was done to examine the amplitude and latency of visual evoked potential elicited from the occipital and temporal regions in children fitted with cochlear implant. Children with congenital hearing loss fitted with CI, with age adequate cognitive development, with normal or corrected to normal visual acuity were included for the study, whereas, Children with post-lingual deafness, with peri-lingual deafness, with any associated disorders like mental retardation, visual impairment and cognitive impairment and children with cochlea and nerve anomaly were excluded. Total number of subjects participated in the study were forty-five children with Cochlear Implant between the age range of four to ten years of age. Forty- four subjects received Med El Sonata with Opus 2 sound processor and one subject received Advanced Bionics HiRes120 implant with Harmony processors in both ears.

Method

Both stimulus and recording parameters were adopted based on the ISCEV standard for visual evoked potentials. Two PC system one for recording and other for stimulation is used. The recording system used is Allengers Scorpio EMG EO NCS system provided by Allengers Medical System Limited, Chandigarh. The stimulation system will provide the pattern reversed stimulus (checkerboard pattern) using and the participant was asked to focus on the red dot at the center of the monitor (Figure 1). Latency of P100 and amplitude of P100 was recorded from Oz, Cz, T5 and T6 was analyzed and compared in the implant age group, and in group with increasing duration of deafness. Participants were selected and grouped in such a manner to rule out the role of critical age in auditory deprivation and to know the neuronal reorganization happening with the increased implant age. One of the cochlear implant users was excluded from further analysis due to outliers in the EEG measurements (VEP amplitude). Among all the subjects one subject was bilaterally implanted. None of the cochlear implant users used sign language as a mode of communication.

Figure 1: Checkerboard pattern with red fixation point.

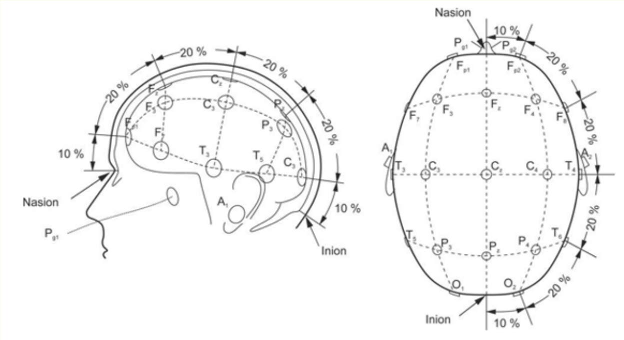

Figure 2: Occipital scalp electrode locations using 10-20 International System. The INION is the skull location at the position shown. The Nasion is on the bridge of the nose, between the eyes.

Recording parameters

System bandpass filter of 2-100hz was used with an Analysis time of 250ms. At least 2 responses should be recorded to check the reproducibility or replicability. The recording electrode used was Standard disk electrode (silver).

Procedure

Based on the bony landmarks (inion and nasion) the disk electrodes are placed on the scalp as per the international 10/20 system (Figure 2).

Electrode montage

The electrode montage used is

- Ground – placed on two ear lobules. (A1, A2)
- Reference – placed on forehead
- Active electrode – placed on 2-4 cm above the inion (Oz), on 2-4 cm above the mastoid bone (T5 and T6) and at Cz (vertex).

After the electrode placement check for the electrode impedance that should not cross 5KΩ. The recording sensitivity was kept at 2μV. The standard pattern reversal (checkerboard) stimulus is given and the participant is placed 50- 150cm away from the monitor. In pattern reversal protocol the black and white checks changesalternatively. The reversal rate used was 1Hz. During the stimulation, the following parameters were recorded

- P100 latency
- N75 latency
- P145 latency
- Amplitude of N75, P100 and N145. These all parameters recorded from Oz, Cz, T5 and T6 was analyzed and compared inthe implant age group.

Results

The data obtained are analyzed using IBM SPAA statistics software 23.0 version. Todescribe about the descriptive statistics, mean and standard deviation was used. For multi variate analysis the Kruskal Walli's test was used and followed by Mann-Whitney U test and for repeated measures the Friedman test was used followed by Wilcoxon Signed rank test. In all the above statistical tools the probability value .05 is considered as significant level.

Amplitude of P100 at recording sites; Oz, Cz, T5 and T6 analyzed withineach GROUP of implant age.

Amplitude of P100 was compared between all recording sites (T5, T6, Cz, Oz), (figure 3). For group1(0-1 years, n = 23), the amplitude was found to be highly significantover the sites. Analysis was done using a nonparametric test; Friedman test. The average amplitude of Oz = 1.73 μV, T6 = 1.21 μV, T5 = 1.07 μV and Cz = 0.74 μV; With a p-value of 0.011.

For GROUP 2(1-2 years, n = 14), The amplitude was found to be highly significantover the sites. The average amplitude of P100 at Oz = 1.56 μV, T6 = 0.95 μV, T5 = 0.90 μV and Cz = 0.69 μV; With a p-value of 0.016.

For GROUP 3(>2 years, n = 8), The amplitude was found to be not significant over the sites. the average amplitude of P100at T6 = 1.29 μV, OZ = 0.9463 μV, T5 = 0.78 μV and CZ = 0.64 μV; With a p-value of 0.522.

Latency of P100 at recording sites; Oz, Cz, T5 and T6 analyzed withineach GROUP of implant age.

Latency of P100 was compared between all recording sites (T5, T6, Cz, Oz). Analysis was done using a non-parametric test; Friedman test. The latency of GROUP 1 (0-1 years, n = 23) was found to be highly significant over the sites. The average latency of P100 at Oz was 110.41ms, T6 was 112.70ms, T5 was 105.64ms and Cz was105.09ms; With a p-value of 0.040. In GROUP 2 (1-2 years, n = 14) the latency was found to be highly significant over the sites. the average latency of P100 at T6 = 115.78ms, T5 = 112.17ms, Oz = 103.89ms and Cz = 97.76ms; With a p-value of 0.000. In GROUP 3 (>2 years, n = 8) the latency wasfound to be not significant over the sites. theaverage latency of P100 at T6 = 106.90ms, T5 = 105.81ms, Cz = 104.24ms and Oz = 98.26ms; With a p-value of 0.533.

Figure 3: The average amplitude and average latency of P100 at Oz, Cz, T5, T6 as the implant age increases; 0-1 years, 1-2 years, 2-9 years.

Figure 4: The average amplitude and average latency of p100 at Oz, Cz, T5, T6 as the implant age increases; 0-1 years, 1-2 years, 2-9 years.

After analyzing the P100 amplitude and latencies of each group it was found that.

The P100 amplitude (Figure 3) and latency (Figure 4) at Oz across the implant age was observed to be decreasing as the implant age increases. The P100 amplitude (Figure 3) at Cz across the implant age was observed to be decreasing as the implant age increases, and latency (Figure 4) was observed that it decreased from age 1-2 years by 5ms and increased by 4ms from age 2-9 years. The P100 amplitude (Figure 3) at T5 across the implant age was observed to be decreasing as the implant age increases and latency (Figure 4) was observed to be increasing from age 1-2 years by 7ms and increased by 6ms from age 2-9 years. The P100 amplitude (Figure 3) at T6 across the implant age was observed to be decreased in age 1-2 years by 0.3 μV and then increased by 0.4 μV towards 2-9 years of age and latency (Figure 4) was observed to be increasing from age 1-2 years by 3ms and decreased by 10ms from age 2-9 years. The amplitude of P100 at T6 reduces as the implant age increases, but at GROUP 3 it shows an increase in amplitude because of the presence an outlier SA38 with amplitude (3.18 μV), without which the amplitude reduces to an average of 1.02 μV. Overall, it suggests that the amplitude and latency of P100 in the temporal cortex reduces as the experience with the implant increase. Also observing the findings within the group, it can be noted that the highest latency of P100 is obtained by the subject with high durationof deafness when compared to the subject with lowest latency.

Categorizing according to duration of deafness

Group with 2-3 years, 5-6 years and 8-9 years of duration of deafness (Figure 5) were taken to compare the amplitude and latency of P100, to get a clear idea of how the cortical changes happen in subject with different duration of deafness on an exposure with cochlear implant. Figure 5 shows the average amplitude of P100 at Oz, Cz, T5 and T6 in groups with 2-3 years, 5-6 years, 8-9 years of deafness. It was observed that as the duration of deafness increases there is a notable decrease in the amplitude of P100. Studying the average latency of P100 at Oz, Cz, T5, T6 in groups with 2-3 years, 5-6 years, 8-9 years of deafness, it was observed that as the duration of deafness increases there is a notable decrease in the latency of P100 in the case of T6, whereas there is a slight increase in the latency at T5, Oz and Cz.

Figure 5: The average amplitude and average latency of P100 at Oz, Cz, T5, T6 in the group with 2-3 y, 5-6, 8-9 years of deafness.

The results also revealed that the amplitude of P100 in VEP in all the recording sites decrease with intense auditory training in the initial few years 0-2 of implantation, compared to the implant age of 2-9 years. there was also a notable decrease in the amplitude but gradually in 2-9 years of implant age.

Discussion

The amplitude of P100 and Latency of P100 are the hallmark of the morphology of VEP. In this study there was a change in the amplitude and latency of P100 across the subjects grouped based on the implant age and deafness duration, the changes were observed in all the recording sites across the groups. All the subjects who participated in the study had congenital hearing loss with minimum duration of deafness 2yrs and maximum duration of deafness 8 yrs. The result obtained in this study shows the change in the latency and amplitude of P100 of the visual evoked potentials in subjects with Cochlear Implants.

The amplitude of P100 was more reduced as the implant age increases supports the fact that as the time in sound of the auditory cortex increases more neurons are recruited for auditory function hence reducing or altering the visual processing capacity of the cortex at large. This finding supports the findings of Bavelier and Neville 2002 [38]. The functional changes induced by auditory experience are not restricted to the auditory cortex that is reorganized by spared sensory modality [37]. The amplitude change in P100 of VEP was also noted when the data was re- analyzed with respect to the duration of deafness. The amplitude of P100 decreased as the duration of deafness increased, since the data size was very small it was very difficult to make a statement on this finding, more over the influence of the electrical stimulation on the deprived auditory cortex was very less understood to make any conclusion based on this finding.

The reduced recruitment of the visual cortical areas in cochlear implant users might be a reason for the reduced amplitudes of P100 component of the visual evoked potential as the implant age increased, indicating either smaller assembly or reduced synchronization of activated neurons in the visual cortex of the cochlear implant users [39]. Cortical reorganization might have advantageous effects during the period of deafness [40], but could have detrimental consequences for the adaption to the new electrical input after Cochlear implantation [37].

In cochlear implantees, despite of the progressive recovery of the auditory function, the superior visual abilities is either maintained or improved [41-44]. The activation of the auditory cortex for visual processing in cochlear implant users may reflect increased cross-modal binding between the visual and auditory system in these individuals. The same was also supported by this study, the latency of P100 reduced as the duration of deafness increased, but there was no such relationship found compared with age at implantation.

After implantation, as the auditory cortex of a congenitally deafened individual not only responds for the auditory stimuli, but also for the visual stimuli. In subjects with longer deprivation of hearing the cross-modal changes of the deaf auditory cortex might hinder its recruitment by the cochlear implant input, if this cortical structure has been functionally re-organized by the spared sensory modalities. As a consequence of this phenomenon, input from the cochlear implant may hinder in the perception of visual cues for speech reading skills of the subject. To overcome this masking or distracting effect of cochlear implant over speech reading skills the subjects might have an internal drive that strengthens the existing bonding between the visual processing skills (i.e., primary visual cortex and associated cortical areas for visual speech and language processing) for perception of speech, thus preventing more neurons and the higher order neural connectomes to associate with electrical auditory signal. This internal drive induced enhanced visual processing in the presence of auditory stimuli might have been a factor that resulted in shorter latency of P100.

The visual induced activation of the auditory regions in cochlear implant users might reflect the residual compensatory reorganization of auditory cortex. Cross- modal reorganization induced by the auditory deprivation may not completely vanish, probably because of the limitation of the capabilities of cortical reorganization, after implantation and leaving a residual cross-modal reorganization which reflects a maladaptive process which hinders the adaptation of the auditory cortex neurons to cochlear implant input [12]. Our findings were in consonance with Sandmann [12], but our justification for reduced latency of P100 is more detailed than the existing explanation by Sandmann [12]. The findings from this study had left a new hypothesis that "the visual processing skills tend to improve as a consequence of electrical input to the auditory cortex via cochlear implant in subjects with longer duration of deafness".

Conclusion

Visual evoked potential (VEP) is an electrophysiological measure that can be used to measure the visual-auditory reorganization in the hearing-impaired population. This study compared VEP activity at different sites of recording in cochlear implant users to examine cross- modal reorganization in the auditory cortex as well as of the visual cortex of cochlear implant users. Despite the varied sample size in the study, the finding suggests the visual processing skills tend to improve as a consequence of electrical input to the auditory cortex via cochlear implant in subjects with longer duration of deafness, as a result of long-term alteration of auditory experience.

The individuals deprived of auditory input can compensate with superior specific abilities in the remaining sensory modalities, in children with short or longer duration of deafness. Auditory cortex can be recruited by other modalities especially visual or tactile function. When subjects receive a new sensory stimulation from Cochlear Implant, the cortex undergoes re-reorganization.

The amplitude of P100 reduces because more neurons are recruited for auditory function hence reducing or altering the visual processing capacity of the cortex and causing reduced recruitment of the visual cortical areas indicating either reduced synchronization or smaller assembly of activated neurons in the visual cortex. The reduction in latencies suggest that auditory experience can alter early, initial stages of visual information processing i.e., it provides information about visual processing time and visual processing skills are either maintained or tend to improve.

The visual induced activation of the auditory regions in cochlear implant users might reflect the residual compensatory reorganization of auditory cortex which hinders its recruitment by the Cochlear Implant input if this cortical structure has been functionally reorganized by the spared sensory modalities. It is very difficult for these subjects to perform the auditory function especially the task which involves complex auditory processing. As a consequence, visual processing skills tend to improve as a consequence of electrical input to the auditory cortex via cochlear implant in subjects with longer duration of deafness.

More detailed and comprehensive experiment need to be conducted to see the effect of visual processing pre and post cochlear implant used with different duration of deafness. This may shed some light in testing the hypothesis and understanding the learning induce plasticity in particular to internal stimulation and peripheral stimulation.

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