CORTICAL ENCODING OF SPEECH AND NON-SPEECH STIMULI IN INDIVIDUALS WITH AUDITORY NEUROPATHY SPECTRUM DISORDER

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This Dissertation is submitted as a part of fulfillment

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CERTIFICATE

This is to certify that this dissertation entitled **'Cortical encoding of speech and non-speech stimuli in individuals with Auditory Neuropathy Spectrum Disorder'** is the bonafide work submitted in part fulfillment for the Degree of Master of Science (Audiology) of the student with Registration No: **17AUD017**. This has been carried out under the guidance of a faculty of this institute and has not been submitted earlier to any other University for the award of any other Diploma or Degree.

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CERTIFICATE

This is to certify that this dissertation entitled **'Cortical encoding of speech and non-speech stimuli in individuals with Auditory Neuropathy Spectrum Disorder'** has been prepared under my supervision and guidance. It is also certified that this has not been submitted earlier to any other University for the award of any other Diploma or Degree.

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DECLARATION

This is to certify that this Master's dissertation entitled **'Cortical Encoding of speech and non-speech stimuli in individuals with Auditory Neuropathy Spectrum Disorder'** is the result of my own study under the guidance of Dr. Ganapathy M K, Lecturer in Audiology, Department of Audiology, All India Institute of Speech and Hearing, Mysore, and has not been submitted earlier in other University for the award of any Diploma or Degree.

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DEDICATED TO MY PARENTS AND ADAM

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ABSTRACT

Aim: To study the cortical encoding of speech and non-speech stimuli in individuals with normal hearing and auditory neuropathy spectrum disorder.

Objectives: To study and compare the speech identification scores and cortical evoked potentials in normal hearing individuals and in individuals with ANSD. Further to study if there is correlation between behavioral measures and electrophysiological measures.

Participants: A total of 40 participants in the study, in which 20 participants had normal hearing sensitivity and the other 20 diagnosed having Auditory Neuropathy Spectrum Disorder. The hearing thresholds of individuals ranged from normal to moderate hearing sensitivity.

Method: Behavioral and electrophysiological measures were carried out. The Behavioral measures used were SNR50 and Speech identification task using monosyllable word list. The objective test was the CAEP i.e., Acoustic Change Complex recorded for speech and non-speech stimuli.

Results: Speech identification scores in individuals with ANSD were deviant in comparison to the normal hearing individuals. All the normal hearing individuals had presence of Acoustic Change Responses where as individuals with ANSD subjects had heterogeneous results. Further, speech in noise scores were severely affected. Speech identifications scores did not correlate to evoked potentials in individuals with ANSD. However, in poor performers, among individual with ANSD the onset response of ACC for speech stimuli were absent.

Conclusion: The results point out ACC can be used as a tool for understanding speech encoding in individuals with ANSD for complex stimuli. Even though there was no statistical significance, the results of ACC showed some correlation i.e, in individuals who had 0% SIS scores, ACC was absent for both the stimuli used. Also, it was seen that LLR were present in all individuals with ANSD but the ACC were affected. This point out ACC as a better tool to study cortical responses in individuals with ANSD

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Chapter 1

Introduction

Auditory Neuropathy Spectrum Disorder (ANSD) has been defined as a hearing disorder described by abnormal auditory nerve functioning in presence of normal cochlear receptor hair cell activity (Starr, Picton, Sininger, Hood, & Berlin 1996). The possible lesion sites being reported are inner hair cells (IHC), junction between IHC and type 1 afferent auditory neurons or afferent auditory nerve itself (Starr et al, 1996; Rance et al at., 1999; Ammatuzzi et al 2001). Reports have shown the hearing sensitivity in individuals with ANSD range from normal hearing to profound hearing loss while approximately 60 to 70% of individuals have speech identification scores well below the identification scores estimated from their pure-tone thresholds (Zeng et al., 2005; Sininger & Oba, 2001).

Studies related to prevalence of auditory neuropathy spectrum disorder varies and is projected that 1 in every 10 children with hearing loss may have ANSD (Sininger, 2002). In India Mittal, et al., (2012) reported the prevalence of ANSD in New Delhi, 5.3% fulfilled the diagnostic criteria for ANSD. Follow up done after 3 months revealed presence of OAEs in 57.6% cases while cochlear microphonics was present in all the cases. Rance et al., (1999) reported that nearly 1 in 9 children with hearing loss were diagnosed having ANSD type and approximately 1 in 433 infants having the risk factors. Kumar & Jayaram, (2006) reported the onset of ANSD being majorly during the first and second decade of life in Indian population

Even though Auditory Brainstem Responses (ABR) have been reported to be absent or grossly abnormal in cases with ANSD, cortical potentials have been reported in most of these

cases indicating the preservation of some useful auditory capabilities (Starr, Picton, Sininger, Hood & Berlin, 1996; Kraus et al., 2000).

Star et al., (1996) found absent or abnormal middle latency responses (MLRs) and Long latency responses (LLRs) in six patients and normal in one patient. Kraus, Ozdamar, Steain and Reed (1984) found absent MLRs in nine ears out of ten ears they evaluated. It was found to be normal in one ear. Narne, Barman, and Sinha (2011) reported that there was a reduction in amplitude of N1 and prolongation in latency in individuals with ANSD and showed correlation with gap detection threshold and speech scores but no correlation with audibility. Narne, Prabhu, Chandan, Deepthi (2014) reported that Late Latency Response being less dependent on synchronous neural firing compared to ABR may be recordable in some cases of ANSD. Hence, the presence of LLR suggests that the neuropathy is limited to the auditory nerve alone, and consequently there are good speech identification scores.

ACC has been rarely studied in clinical population. Srikar and Narne (2011) investigated Acoustic Change Complex measures in individuals with Auditory Neuropathy Spectrum Disorders. They used speech stimuli. They observed that individuals who demonstrated the presence of ACC had good speech recognition abilities compared to individuals with absence of ACC. Also latency and amplitude measures were significantly affected in individuals with auditory neuropathy compared to normal listeners. Kumar and Jayaram (2005) reported MMN in individuals with auditory neuropathy and reported that strong correlation between speech perception abilities and temporal processing deficits, in most of individuals with ANSD. It could be elicited with normal amplitude and latency.

Multiple overlapping cortical evoked potentials (CAEPs) can be recorded for a complex stimulus which has change/s within the ongoing stimulus and this is called as Acoustic Change Complex (ACC) (Ostroff, Martin, & Boothroyd, 1998). The ACC can be elicited in response to spectral and intensity changes within a speech or non-speech stimuli (Ostroff, Martin, & Boothroyd, 1998; Martin and Boothroyd, 1999; Tremblay, Friesen, Martin and Wright, 2003). The latency and amplitude of cortical potentials showed a significant correlation with open set speech perception abilities (Narne & Vanaja.; 2008; Zeng et al., 2009; Vanaja & Manjula, 2004).

The first auditory evoked potential study in patients with auditory neuropathy was done by Kraus et al (1983). He described ABR abnormalities with was out of proportion with the audiometric findings. MLR was normal 1/5 individuals with ANSD, the rest 4 reported to have MLR absent. Hence a neuropathology of brainstem was suspected in these patients.

Kaga et al. (1996) reported patients with ANSD having absence of ABR but broad compound action potentials on EcocG and almost normal OAEs along with absence of caloric responses. The audiometric results in these individuals showed hearing loss mild hearing loss and markedly poor scores in speech audiometry.

The acoustic change complex (ACC) has been described as a cortical auditory evoked potential elicited in response to a change in an ongoing sound. The P1-N1-P2 recorded from the auditory cortex following the presentation of an acoustic stimulus is believed to reflect the neural encoding of a sound signal.

ACC can be recorded for changes in amplitude, spectral and envelop/periodicity in normal hearing population (Ostroff & Martin, 1998). In addition, the ACC can be reliably recorded with good test-retest reliability not only from listeners with normal hearing but also

from individuals with hearing loss, hearing aids, and cochlear implants (Tremblay, Friesen, Martin and Wright, 2003; Martinez, Eisenberg, & Boothroyd, 2013). The ACC can be obtained even in the absence of attention and requires relatively few stimulus presentations to record a response with a good signal-to-noise ratio. Most importantly, the ACC shows reasonable agreement with behavioral measures and may serve as a clinical measure for assessing speech perception capacities (Kim, 2015).

This study aims to utilize the ACC as a tool to study the cortical encoding of speech and non-speech stimuli in individuals with ANSD and in turn correlate with speech identification scores.

1.1 Need for the study

Speech perception in individuals with ANSD is poorer than what could be predicted from the pure tone average. Though auditory brainstem responses are absent in individuals with ANSD, cortical potentials can be used as a measure. The studies were done by Rance et al., (2004), Vanaja & Manjula (2004) and Dimitrijevic et al., (2010) have provided evidence that individuals with ANSD who demonstrate cortical potentials show better speech perception scores and show benefit with amplification.

Currently, there is no other objective tool which can quantify their ability to perceive or encode changes in an ongoing stimulus, which is a fundamental aspect of speech understanding. Hence, this present study will be carried out by recording cortical potentials for complex stimulus with change/s within the ongoing stimulus, in individuals with ANSD. Further, the CAEP results will be compared with the behavioral scores.

1.2 Aim

To study the cortical encoding of speech and non-speech stimuli in individuals with normal hearing and auditory neuropathy spectrum disorder.

1.3 Objectives

1. To examine the performance of speech identification scores in normal hearing individuals and in individuals with ANSD

2. To investigate the cortical evoked potentials in normal hearing individuals and in individuals with ANSD

3. To correlate the SIS scores with cortical evoked potentials in normal hearing individuals and in individuals with ANSD

4. To compare the cortical encoding of speech and non-speech stimuli in normal hearing individuals and individuals with ANSD

1.4 Hypothesis of the study

Null hypothesis is assumed for the present study:

1. There is no correlation between the speech identification scores and cortical evoked potential in normal hearing individuals and in individuals with ANSD.

2. There is no difference between the results of cortical encoding of speech and non-speech stimuli in normal hearing individuals and in individuals with ANSD.

Chapter 2

Review of Literature

Auditory Neuropathy spectrum disorder (ANSD) has been defined as a condition with abnormal retro outer hair cell functioning that is, neural transmission in the auditory pathways is disordered but cochlear amplification function is normal. It was described by Starr et al at 1991 in one subject and this was followed by a report on a series of subjects with similar symptoms (Starr et al). Since then, much research has gone into understanding the nature of this condition.

2.1. Profile of patients with Auditory Neuropathy Spectrum Disorder

2.1.1. Onset and course. Sininger and Oba (2001) studied a group of 59 individuals with auditory neuropathy and reported a mean age range of onset as 9 years. 75% of their patients were less than 10 years of age when the first symptom of auditory neuropathy was seen. Some subjects develop the ANSD condition in adolescence or early adulthood. The course is quite unpredictable and the condition may stay the same, revolve, fluctuate or worsen over time.

2.1.2. Prevalence. The estimate varies from roughly 1% (Foerst et al, 2006) to 10% in schools for the deaf (Berlin et al, 2000; Lee et al, 2001; Cheng et al, 2005) and between 10% in newborns (Rea & Gibson, 2003) report a prevalence of around 0.53% among adults with sensory neural hearing loss in India.

The prevalence of auditory neuropathy spectrum disorder varies according to studies and is estimated 1 in every 10 children with hearing loss may have ANSD (Sininger, 2002). In India Mittal, Ramesh, Panwar, Nilkanthan, Nair and Mehra, (2012) reported a study done at New Delhi, reported the prevalence and audiological characteristics of auditory neuropathy. Out of 487 pediatric cases 26 cases (5.3%) fulfilled the diagnostic criteria for ANSD. Rance and

colleagues (1999) reported that nearly 1 in 9 children with hearing loss were of the AN type and approximately 1 in 433 (2.3 per thousand) infants with risk factors have AN.

2.1.3 Causes of ANSD. Manchaiah, Zhao, Danesh, and Duprey (2011) Individuals with ANSD has been considered multifactorial. They also reported that a large of ANSD is inherited genetically which could be syndromic, non-syndromic or mitochondrial related. For example, mutations of genes namely OPA1, OTOF etc are found to be non-syndromic causes for ANSD. Other proposed causes in children include prematurity, anoxia (Berlin et al, 2010), genetic mutations and hyperbilirubinemia (Madden, Hilbert, Rutter, Greinwald, & Choo, 2002). In late onset ANSD, infections (measles, mumps), any neurological conditions with peripheral neuropathy (Eg. Fredreich Ataxia, Charcot-Marie-Tooth disease, etc) and demyelination conditions such as multiple sclerosis and HIV infection (Manchaiah. et al., 2011) are reported to be etiologically related. Predisposing factors for late onset ANSD may comprise of low socioeconomic status, exposure to toxic chemicals, family history of the condition, and onset at the pubertal age (Prabhu, Avilala & Manjula, 2012).

2.2 Audiological Profile

The ANSD subject group is highly heterogeneous in nature. Correspondingly, their audiological profile is highly variable. Some trends are given below

2.2.1 Pure tone audiogram. Most patients present with bilateral hearing loss, Berlin et al, 2010 reported that 77% of their 103 subjects had a symmetrical hearing loss while the rest 23% had an asymmetrical presentation.

Starr et al (2000), in a study of 67 patients with ANSD , reported flat audiograms in 41%, reverse sloping audiogram in 29%, an irregular saw-tooth pattern in 9%, U-shaped audiogram in

5% and a tent shaped audiogram with a peak usually at 2 kHz in 5% of the patients. Narne, Prabhu, Chandan and Deepthi (2014) reported out of 198 patients, reliable ear-specific pure tone thresholds could be obtained in only 176 patients. The degree of hearing loss ranged from normal to profound. Among the 176 patients, pure tone thresholds were symmetrical in 105 and asymmetrical (difference in pure tone average between ears was more than 20) in 71 patients. Out of 176 patients only 28 ears showed a peaked audiogram, 62 ears showed flat audiograms, 137 ears showed a rising configuration, 78 ears showed a saucer-shape and 47 ears showed a sloping audiogram.

2.2.2 Speech Perception. Drastically affected in individuals with ANSD, particularly in the presence of noise. It has been noted that patients with ANSD have speech perception abilities that are out of proportion with their pure tone hearing loss. (Li, Wang, Chen & Liang 2005; Starr et al, 1996)

Speech perception abilities affected in noise in individuals with ANSD (Shallop, 2002; Zeng & Liu, 2006). The speech identification scores (SIS) of individuals with ANSD may range from 0 to 100% in quiet (Berlin et al., 2010; Kumar & Jayaram, 2006; Kraus et al., 2000). These speech perception difficulties are more affected in the presence of noise (Rance et al., 2007, Kraus et al., 2000).

2.2.3 Acoustic Reflexes. Starr et al., (1996) reported individuals with ANSD usually have absent stapedial reflexes. The middle ear or stapedial reflex or acoustic reflex is mediated by the inner hair cell, eight nerve and brainstem pathways. The absence of the acoustic reflex and the presence of OAEs therefore reflects some pathology at some point in this pathway. Absence

of both ipsiltateral and contralateral reflexes were reported in these individuals (Kumar & Jayaram, 2006)

2.2.4 Otoacoustic emissions. Normal functioning of the outer hair cells correlated with robust OAEs in those with ANSD. (Berlin et al, 2010). However, in some individuals with ANSD, OAEs may disappear over time (Starr, Sininger & Pratt 2000). Hood and Berlin (2001) have noted that the amplitude of TEOAEs in individuals with normal hearing. The high amplitude has been attributed to lack of efferent suppression (Sinninger & Starr, 2001)

In a study done by Narne et al. (2014) where they evaluated OAEs and cochlear microphonics for both ears in 198 individuals, it was found that approximately three-quarters of the patients had present OAEs while the remaining one-quarter had either partial or absent responses. However, in a quarter of the patients in whom OAEs were partial/ absent, cochlear microphonics were present.

It was observed that the occurrence of SOAEs was higher frequencies below 1.5 kHz in individuals with ANSD compared to individuals with normal hearing. It was also observed that greater number of individuals with ANSD had SOAEs present at multiple frequencies in comparison to those with normal hearing. (Mallat, 1989). The reasons thus reporting saying that individuals with ANSD may have some subtle auditory dysfunction at the level of the outer hair cells (OHCs) responsible for cochlear active mechanism (Narne, Prabhu, & Chatni, 2014).

Narne, Prabhu and Chatni (2014) carried out time frequency analysis of Transient Evoked Otoacoustic Emissions (TEOAEs) in 22 individuals with ANSD. Findings between individuals with ANSD and a normal group. Higher amplitude TEOAEs, with slightly shorter latencies for lower frequency signals than the normal control group were found in the clinical group which was also thought to be caused by damage to the efferent system.

2.2.5 Cochlear Microphonics. Typically robust and present for several milliseconds after the transient click (Berlin, 1999l Delantre et al, 1998; Duan & Wang 2002; Starr et al 1996; Starr et al 2000; Santarelli & Arslan, 2002). Starr et al (2001) reported abnormally increased CMs were found only in those AN subjects less than 10 years of age also phase reversed components continued out to 3 msec whereas in the healthy control phase reversed components after 0.7 msec could not be distinguished as CMs from latency-shifted neural components. Aand A SP was identified in approximately 50% of both AN (28 out of 57). The average peak amplitude of the SP in AN was 0.11 mV with a peak latency of 0.75 msec.

2.2.6 Auditory brainstem responses. Starr et al (2000) reported that 70% of their patients did not show any component of ABR regardless of the level of the stimulus. Krus et.al., (2000) presented a case of 24 year old woman with normal hearing thresholds, robust OAEs and 100% speech recognition scores in quiet. The performance, however drastically reduced in the presence of noise. Wave I was absent and waves III and V were present inconsistently and had a poor morphology, latency and amplitude. It was hence concluded that optimal auditory nerve and brainstem synchrony was not necessary in quiet, but was important in the presence of noise.

2.3 CAEPs in estimating of hearing thresholds

2.3.1. CAEPs in normal hearing individuals. Cortical auditory evoked potential (CAEPs) reflect synchronous neural activation of structures in the thalamic-cortical division of the central auditory system (Souza & Trembley, 2006). Estimating hearing thresholds in difficult to test population, measuring outcome with hearing devices, assessing ANSD assessing central auditory processing, monitoring improvement/ changes in auditory processing with use of hearing devices and/ or auditory training would be the clinical application of CAEPs.

The lowest intensity at which replicable response could be obtained is the CAEP threshold and this can be used to predict behavioral threshold. It has been reported that CAEP threshold is usually 5-10 dB higher than the behavioral threshold. (Lightfoot & Kennedy, 2006).

2.3.2 CAEPs potentials in SNHL. Oates, Kutzberg and Stappells (2002) recorded N1, MMN, N2 and P3 along with behavioral measures to speech sounds /ba/ and /da/ presented at 65 and 80 dBSPL in normal hearing as well as in those with SNHL varying in degree (1 to 2kHz) from mild to profound hearing loss. They reported that as long as the stimulus presented was 12dB above the average threshold of 1000 and 2000Hz the amplitude parameters remained stable. However, latency was prolonged even with mild threshold elevation. The amplitude changes which occurred with reductions in intensity was more for the later ERP peaks like N2 and P3 and behavioral discrimination measures that the initial responses like N1 and the MMN. They also reported an intriguing finding that the grand average waveform of those with moderate hearing loss had greater amplitudes for N1 and P3 than the normal hearing group at high presentation levels.

Polen (1984) found that moderate to severe sensorineural hearing loss resulted in the prolongation of N1, P2 and P3 latencies and a reduction in N2 amplitude. In contrast Wall et al reported no significant differences between normal and mild to moderate SNHL subjects for latency but corroborated the reduction in amplitude of N1.

2.4 CAEPs in measuring outcome with hearing aids

Berlin et al., 1996 reported that conventional amplification may simply produce louder, but distorted signals that may not compensate the temporal processing deficits in ANSD. Hence researchers recommend proceeding cautiously with amplification for ANSD. (Hood, 1998). Recent studies showed significant improvement in aided speech perception, especially in children. Rance and Colleagues (2009)

Trembley, Kalstein, Billings and Souza (2006) reported that CAEPs can be used as an indicator to check whether the signal is audible and this can help in validating the benefit from hearing aid/s. They observed very subtle increase in amplitude of CAEPs when the hearing aid was provided with mild high frequency gain.

Korezak and Stapells (2010) reported that the use of hearing aids markedly improved the detectability of CAEPs and a majority of individuals with hearing impairment showed reduced latency, enhancement in amplitude and improved morphology when tested with their hearing aids. Vanaja and Khandelwal (2016) also observed that the detectability of CAEPs to speech stimuli presented at 65dB SPL increased with the use of hearing aids specifically in persons having moderately-severe to severe hearing loss.

Other studies indicate that N1-P2 complex can be an index of performance with hearing aids. Koul and Vanaja (2010) observed significant correlation between functional gain of hearing aids and morphology of CAEPs

2.5 CAEPs in persons with cochlear implants

CAEPs can be used in deciding the candidacy of cochlear implants and predicting the usefulness of cochlear implants in children. Roland, Henion, Booth, Campbell and Sharma

(2012) explained the usefulness of P1 biomarker in determining cochlear implant candidacy in children with cochlear nerve deficiency. CAEPs recorded from cochlear implant users. (Sharma et al., 2005) have indicated that the latency of P1 can be used as a biomarker of development of central auditory pathway in children with hearing loss using cochlear implants. The results show the latency and amplitude of P1 depends on the age of implantation.

Friesen and Tremblay (2006) reported that ACC is also recordable in cochlear implant users and thus implying that the central auditory functioning of cochlear implant users can be recorded for complex auditory stimuli.

Acoustic change complex can be recorded in cochlear implant users and had robust responses to large changes in second formant frequency and showed reasonable agreement with behavioral change measure which indicates a positive potential clinical application of the ACC to individuals with cochlear implants.

Evidence from literature indicates that CAEPs help in deciding candidacy for cochlear implantation. Absence of CAEPs with hearing aids (aided CAEPs) in children with normal radiological findings suggests that hearing aids may not be providing sufficient gain to enable them to hear. Cochlear implantation may be a choice of rehabilitation in such children.

Punch, Van Dun, King, Carter, and Pearce (2016) described the CAEP protocol followed in clinics of Australian Hearing for infant hearing aid evaluation. The protocol includes recording CAEPs for /m/, /t/ and /g/ at 55 dB SPL, 65 dB SPL and 75 dB SPL.

2.6 CAEPs in persons with central auditory processing disorders

Studies on children with dyslexia learning problem/ have reported in the literature to abnormal CAEPs signifying the auditory processing being deviant. (Cunningham, Nicol, & Zecker, Bradlow &Kraus, 2001; Wible, Nicol & Kraus, 2002). Literature point to that CAEPs recorded in presence of noise is more sensitive in identifying auditory processing problem when compared to CAEPs in quiet CAEPs are useful in reporting auditory plasticity effects, it can also account for the changes in organization of central auditory system that has occurred with rehabilitation, either through use of hearing devices (Purdy & Kelly, 2016) or with auditory training (Trembley &Kraus, 2002; Trembly, Shahin, Picton & Ross 2009; Vaidyanathan, 2015; Vanaja & Maruthy, 2004)

2.7 CAEPs in individuals with Auditory Neuropathy Spectrum Disorders

Starr et al., 1996 reported that the condition of ANSD results in absent or grossly distorted ABRs but the cortical potentials can still be recorded in many of these individuals. This is because the ABRs are typically action potentials and have fast time constants, typically around 1ms. So, synchronous firing of neurons is very essential for the action potentials to generate a far field potential which can be recorded at the vertex. The cortical potentials on the other hand, are dendritic potential and have large time constants in tens of millisecond. They are hence less dependent on synchrony Also, the cortical neurons are greater in number and much nearer to the scalp. Hence, cortical potentials can still be recorded in most subjects with ANSD.

Narne & Vanaja (2008) used click stimuli to evoke cortical evoked potentials in ANSD. They divided their subjects into good and poor performers based on their speech recognition abilities. They noted that N1-P2 amplitude was significantly greater in the good performers when

compared to the poor performers. They did not find a significant correlation between N100 latency and speech perception scores.

Rance et.al., (2002) investigated the relationship between speech perception and cortical potentials in 18 children with ANSD. Results indicated that 50% of the children had open set speech recognition scores similar to those with SNHL and the other 50% of the children had no measurable open set speech recognition. They found that children in the former group had recordable cortical potentials and derived significant benefit from amplification while the latter had absent responses and failed to get appreciable benefit from amplification. Manjula and Vanaja (2004) reported similar results in their adult subjects with ANSD.

Dimitrijevic et al (2010) did a study on the representation of frequency and intensity changes of continuous tones at the cortical level in 10 subjects with ANSD. They reported that ANSD subjects demonstrated N100 only for large changes in frequency and intensity in comparison to normals. Furthermore, N100 latency in these subjects was significantly delayed compared to normals, more so for 250Hz than for 4000Hz and more so for changes in intensity rather than frequency. The amplitudes were also significantly reduced in all, except for pre-synaptic dysfunction subjects in whom amplitudes were greater than controls. The authors attribute this to abnormal adaptation in the presynaptic dysfunction group

Studies have reported that the presence of CAEPs may be present in many individuals with ANSD the reason being that requires a smaller amount of synchronous firing when compared to Auditory Brainstem Responses (Kraus et al., 2000; Kumar & Jayaram, 2005; Narne and Vanaja, 2008; Singh & Barman, 2010; Vanaja and Manjula, 2004; Yuvaraj &

Mannarukrishnaiah, 2015). The presence or absence of CAEPs may be taken as a pointer of severity of ANSD.

Narne and Vanaja (2008) reported that the amplitude of N1-P2 complex in individuals with ANSD and that it correlates with speech scores, signifying that CAEPs may aid in predicting perceptual skills in this population. Narne, Barman and Sinha (2011) reported that prolongation in latency and reduction in amplitude of N1 observed in person with ANSD correlate with word recognition score and gap detection threshold but not with audibility.

Sharma, Glick, Deeves and Duncan (2015) reported that children with ANSD can be categorized as having mild, moderate or high level of dysynchrony based on the P1 responses. Normal P1 responses indicative of having mild dysynchrony while delayed and low amplitude P1 indicative of having moderate dysynchrony. They further put forward that absent P1 in an individual with ANSD is suggestive of a high level of dysynchrony.

These literature indicate the cortical potential as a biomarker which can be used to study the encoding of stimulus in cortex and the amount of dysynchrony or even the speech perception ability in individuals with ANSD. The current study the cortical potential ACC is recorded for complex speech and non-speech stimuli. The responses elicited for these rapidly changing stimuli can further give insight into the cortical encoding in individuals with ANSD. Further, there are limited studies which have systematically studied the ACC in comparison to the speech scores.

Chapter 3

Method

The method included recording of cortical encoding of participants with auditory neuropathy spectrum disorder and in normal hearing individuals using both speech and non-speech stimuli. Further behavioral speech identification scores will was obtained to classify ANSD individuals and will be compared with the cortical responses.

3.1 Participants

This study consisted of two groups of participants. Group 1 consisted of participants with normal hearing and Group 2 had individuals with ANSD.

3.1.1 Normal hearing subjects (Group1). The participants of this group constituted of 20 individuals with normal hearing in the age ranging from 20 to 40 years (Mean age = 21). The pure thresholds were <15dBHL for the frequency range of 250Hz-8000Hz for air condition and 250Hz-4000Hz for BC stimuli.

Speech identification scores were above 90% in both ears. The participants with 'A' type tympanogram bilaterally with reflexes present at 1000Hz were included in the study.

3.1.2 ANSD Subjects (Group 2). The participants of this group consisted of 20 individuals diagnosed with ANSD (at AIISH, Mysuru) in the age range of 20 to 40 years (Mean age = 25). The hearing sensitivity of individuals with ANSD were not greater than moderate degree. Subjects demonstrating the presence of otoacoustic emissions and/or cochlear microphonics along with the presence of late latency responses and the absence of auditory brainstem responses were included in the study. Based on the speech identification scores of the participants they were classified as good performers and poor performers. Table 3.1 depicts the

demographic details of the 20 individuals diagnosed having auditory neuropathy spectrum disorder.

Table 3.1

Demographic details and degree of hearing loss of individuals with ANSD

Participant	**Age/Gender**	**Hearing Sensitivity**
AN1	20Y/Male	Minimal HL
AN2	25Y/Male	Mild Hearing Loss
AN3	20Y/Female	Moderate Hearing Loss
AN4	20Y/Female	Moderately Hearing Loss
AN5	25Y/Female	Mild Hearing Loss
AN6	49Y/Female	Moderate Hearing Loss
AN7	32Y/Male	Normal Hearing Sensitivity
AN8	24Y/Female	Mild Hearing Loss
AN9	36Y/Female	Mild Hearing Loss
AN10	21Y/Female	Moderate Hearing Loss
AN11	20Y/Male	Minimal Hearing Loss
AN12	20Y/Female	Mild Hearing Loss
AN13	20Y/Male	Moderate Hearing Loss
AN14	21Y/Male	Moderate Hearing Loss
AN15	24Y/Female	Mild Hearing Loss
AN16	26Y/Female	Mild Hearing Loss
AN17	31Y/Female	Moderate Hearing Loss
AN18	26Y/Female	Minimal Hearing Loss
AN19	20Y/Male	Moderate Hearing Loss
AN20	32Y/Female	Moderate Hearing Loss

3.2 Test environment

All the tests were carried out in a sound-treated room where the noise level as per the guidelines of ANSI S3.1 (1991) standards.

3.3 Instrumentation

1. A clinical audiometer- Inventis Piano calibrated according to ANSI standards 1996 with TDH39 earphones housed in MX/41 AR, ear cushions were used to estimate air conduction thresholds and Radio ear B71 bone vibrator were used to estimate bone conduction thresholds.
2. A calibrated Grason Stadler Tympstar Immittance was used for tympanometry and reflexometry.
3. Intelligent Hearing Systems (IHS) opti- amp evoked potential instrument with smart EP version 3.94 USBeZ software to elicit and measure evoked potentials.

3.4 Procedure

The study was carried out using behavioral measures and electrophysiological measures.

3.4.1 Behavioral measures

SNR 50*:* The levels of speech presentation through the audiometric headphones were kept constant at 45dBHL and in participants with ANSD the level was in accordance with the hearing loss. The initial level of speech babble was kept at 15dB HL below that of the speech i.e. at 30dB HL. The level of speech babble was increased in 5dB steps until the participant repeats at least twelve out of twenty-five (i.e. 50%) words being presented. For this, the speech was varied in 2dB steps in order to obtain a precise level of speech babble at which 50% of the

words will be repeated correctly. At this instance, the difference between the speech and speech babble was noted as the SNR 50 measure.

Speech Identification Task: The participants were instructed to repeat the words heard. The presentation level was 40 dB SPL with no background noise. Using monosyllable word list in Kannada developed by Mayadevi (1978) Appendix I and phonemically balance word list in Kannada developed by Yathiraj &Vijayalakshmi (2005) Appendix II.

3.4.2 Electrophysiological measures. The participants were seated in an acoustically treated room [ANSI S3.14991(R-2003)]. A skin abrasive paste was used to clean the electrode sites (Cz: Non inverting; mastoid: inverting and Fpz: Ground) and AgCl disc electrodes with conduction gel were placed and attached using a surgical tape. Presence of late latency response (LLR) was taken as selection criteria for individuals with auditory neuropathy spectrum disorder. The LLR were obtained for 1 kHz at 80 dBnHL. All the 20 individuals with ANSD had LLR present. In the Figure 3.1 shows LLR elicited in an individual with ANSD, which shows a clear P1, N1 and P2 response. In a four point rating scale (4 being very good and 0 as no response) rated by three experienced audiologists, 13 were rated 4, 2 were rated 3, 1 were rated 2 and 4 waveforms were rated 1.

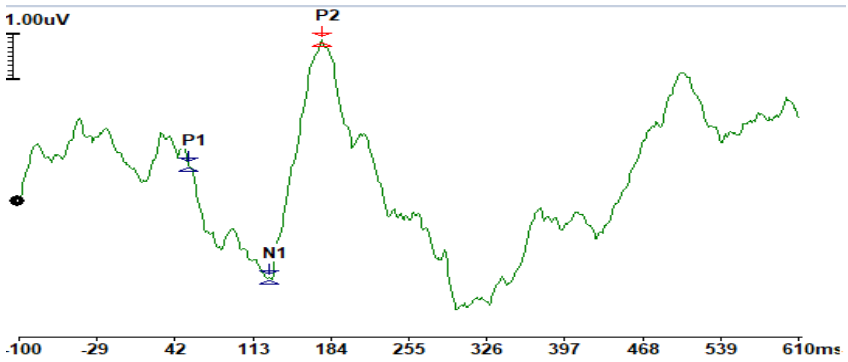


Figure 3.1. LLR waveform of an Individual with Auditory Neuropathy

The ACC were recorded in normal hearing individuals and in ANSD subjects using speech and non-speech stimuli. The speech stimulus was a consonant-vowel (CV) monosyllable /sa/ (Figure 1), naturally recorded from an adult male native Kannada (south Indian Dravidian language) speaker. The stimulus was recorded in a sound-treated room using a dynamic unidirectional microphone (placed at a distance of 10 cm from the speaker), using a personal computer with a 16-bit resolution sound card at a sampling rate of 44,100 Hz. The recorded CV was normalized and edited to have a total duration of 372ms. The consonant /s/ and /a/ duration is 150ms each. The duration of consonant portion /s/ was 149.6 ms, consonant vowel boundary was 2 ms, transition duration was 65.4 ms, Vowel duration (steady portion /a/) was 157 ms and total duration of /sa/ was - 372 ms.

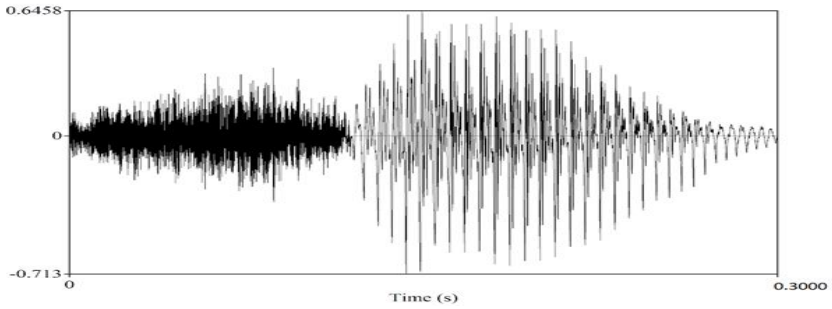


Figure 3.2: Waveform of speech stimulus /sa/

The non-speech stimulus consists of white noise followed by 1 kHz tone having the same spectral envelop and rms intensity. The white noise and I kHz duration was 150ms each. A ramp of 10ms was introduced for smooth transition from noise to tone.

The aperiodic noise stimulus will have a continuous spectrum whereas the periodic stimulus will have a line spectrum. The stimulus was then digitized at 12 bits and 22050 samples per second. It was presented to the participants monaurally at 80 dB SPL.

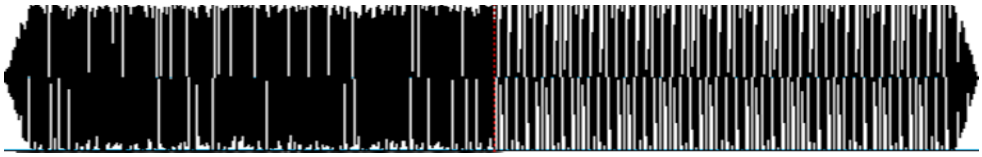


Figure 3.3: Waveform of non-speech stimulus with white-noise followed by a 1kHz tone

For stimulus presentation and data recording, 4 channel Intelligent Hearing Systems (HIS) Smart EP version 3.95 was used. The stimuli were presented using ER-3A insert earphones and calibrated at 80dB SPL. A repetition rate of 1.1/sec was used and the electrode impedance was maintained at ≤ 5k Ω and inter-electrode impedance at ≤ 2KΩ. The participants were asked to relax and was made to watch a film in the absence of audio with the use of a battery operated laptop.

Table 3.2

Stimulus and acquisition parameters for recording ACC

Stimulus Parameter		**Acquisition Parameter**	
Speech stimulus	/sa/ a total of 300msec	Analysis time	-100ms to 600ms
Non-speech stimulus	White noise followed by a 1kHz tone.	Filter	1-100Hz
Stimulus level	80 dB SPL	Number of channels	2 channels
Polarity	Alternating	Sweeps	200

Transducer	Insert earphones ER-3A	Electrode impedance	≤5kΩ
Repetition rate	1.1/sec	Inter Electrode Impedance	≤2kΩ
Mode of presentation	Ipsilateral presentation	Number of recordings	2 for replicability
		Notch filter	Off
		Artifact rejection	75µV
		Amplification	50000

3.5 Response analysis

Speech identification scores were calculated for both the behavioral tests. Analysis of waveforms for speech and non-speech stimuli was done in terms of latency and peak-to-peak amplitude. The latency of onset response (N1 and P2) and change response ($N1^1$ and $P2^1$) were tabulated and analyzed. Furtheron peak-peak amplitude of onset and change responses N1-P2 and $N1^1$-$P2^1$ respectively was analyzed.

3.6 Statistical Analysis

Normality of the data was checked using Shapiro-Wilk normality test. Based on the results of normality test, parametric independent 2 sample t-test was carried out to see the significant difference between normal hearing subjects and individuals with ANSD to study the ACC responses. Pearson's correlation was carried out to check if there was a relationship between the speech identification scores and the evoked potentials.

Chapter 4

Results and Discussion

The aim of this study was to investigation the cortical encoding of speech and non-speech stimuli in individuals with normal hearing and auditory neuropathy spectrum disorder. ACC was elicited using two stimuli speech /sa/ and non-speech (noise followed by 1 kHz). The latencies and peak to peak amplitudes of the responses were calculated for both the groups and tabulated. To investigate the objectives of the study, the following statistical analysis were done.

- To find out the differences in performance of speech identification scores in normal hearing subjects and ANSD subjects.
- To find out if there was a significant difference between in latency and peak-to-peak amplitude between the control group and the ANSD subjects a parametric independent 2 sample t test was carried out.
- To find out if there was a correlation between latency and amplitude parameters of the cortical potential and the speech identification (SI) scores in the ANSD group, Pearson Correlation test was done separately for both the stimuli.
- To find out if there was a significant difference between the speech and non-speech stimuli in normal hearing individuals and ANSD.

4.1 Performance of speech identification scores in normal hearing subjects and in individuals with ANSD

As all normal hearing subjects had a 100% score for speech identification, thus statistical analysis was carried out. Normal hearing individuals had a speech identification score of 100% while the speech identification scores in individuals with auditory neuropathy ranged from 0% to 74% scores. (Mean= 34.85) These results indicate that speech identification for individuals with

ANSD in quiet is also affected. The individuals having auditory neuropathy had hearing loss ranging from minimal to moderate hearing losses in the current study but the speech identification scores had no association with the degree of hearing loss. For example an individual with mild hearing loss had 0% where as a participant with moderate hearing loss had 48% speech identification scores. Sininger, Oba (2001) reported that most of the individuals with auditory neuropathy have the loss in the low frequency end which is also inconsistent with their speech recognition scores for the degree of hearing loss. The range varied from 60-70% of individuals having identification scores below the estimated identification from their pure tone thresholds.

The other main characteristic of AN is a significantly impaired capacity for temporal processing and difficulty in speech understanding, particularly in noise, that is disproportionate to the degree of hearing loss measured by pure-tone thresholds (Kraus et al., 2000; Rance, ConeWesson, Wunderlich, & Dowell, 2002; Rance, McKay, & Grayden, 2004; Zeng, Kong, Michalewski, & Starr, 2005; Zeng, Oba, Garde, Sininger, & Starr, 1999).

Hood (2011) reported Behavioral responses are variable as shown by audiometric configurations from normal to profound ranges and variable but generally poor speech recognition, particularly in noise. ANSD patients fall between these two extremes, showing inconsistent auditory responses with best responses in quiet and poorest in noise. Their audiograms can be misleading or fluctuate.

Zeng, Oba, Grad, Sininger (1999) & Rance (2005) the possible reason quoted for this poor speech identification was disturbed neural synchrony, which in turn impairs the listeners

ability to processes the dynamic nature of speech signals. It was also reported that this impairment further on disrupts the ability to use the envelop cues in speech.

Among individuals with auditory neuropathy spectrum disorder SNR50 were carried out. Only 13/20 individuals were able to perform and the results were highly variable ranging from +22 to +48 SNR (Mean=32.15, SD=7.48). SNR50 has been reported in various studies in normal hearing individuals. Manjula and Megha (2012) reported the mean SNR-50 in normal hearing adults was -7.23 with the standard deviation of 3.65. The median of the SNR-50 for normal hearing individuals was -7.00. These results indicate that individuals with have severe listening problem in presence of background noise.

Zeng & Liu, (2006) reported speech perception abilities affected in noise in individuals with ANSD. The material used for this was BKB sentences and the noise with a speech-spectrum-shaped noise at signal to-noise ratios (SNRs) from 0 to 15 dB in 5 dB step

Narne, Barman, Deepthi & Shachi (2014) reported speech recognition thresholds in noise were measured using Quick SIN in both normal hearing and listeners with ANSD. In listeners with ANSD, the average threshold was 4.4 dB, which is a 9-dB higher SNR than normal-hearing listeners.

The results of this particular data that has been examined the differences between the speech scores in normal and individuals with ANSD showed variations. Individuals with ANSD had affected speech identification scores in quiet and severely affected in the presence of noise.

4.2 Cortical evoked potentials in normal hearing individuals and in individuals with ANSD

The Acoustic change complex of normal hearing subjects had robust responses for both the speech and non-speech stimuli. The nomenclature used to name the peaks has varied

throughout the literature (Ostroff, Martin & Boothroyd, 1998; Tremblay, Billings, Friesen, 2006). In this study, we have utilized the nomenclature of naming the onset response N1 and P2 and $N1^1$ and $P2^1$ for the change response. The results will be discussed based on the speech and non-speech stimuli used for eliciting ACC /sa/ and white noise followed by a 1kHz tone.

4.2.1 Speech stimuli

The /sa/ stimuli elicited Acoustic change complex in all 20 normal hearing subjects. Similar to the present study, previous investigators (Ganapathy, Narne, Kalaiah, Manjula 2013 & Ganapathy & Manjula, 2016) reported that ACC was present in all of their normal hearing subjects. Tables 4.1 and 4.2 depicts the latency and peak-to-peak amplitudes of onset and change response for speech stimuli in normal hearing individuals

Table 4.1

Mean and standard deviation of latency for normal hearing subjects for speech stimuli

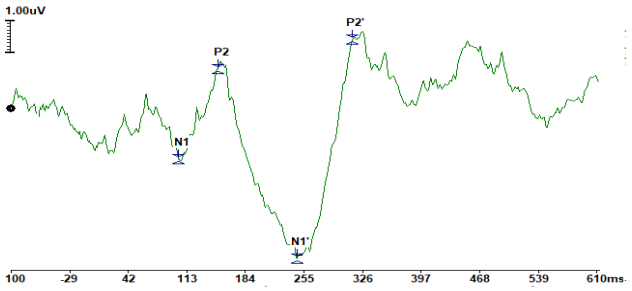
Peaks	**Mean latency (ms)**	**SD for Latency (ms)**
N1	115.3	9.4
P2	148.4	19.4
$N1^1$	263.9	12.4
$P2^1$	322.2	18.54

Table 4.2

Mean and standard deviation of peak-to-peak amplitude for normal hearing subjects for speech stimuli

Peaks	**Mean amplitude(µV)**	**SD for amplitude(µV)**
N1P2	3.07	1.0
$N1^1P2^1$	3.5	0.93

In the Figure 4.1 ACC for speech stimulus /sa/ of three individuals (a,b,c) is shown. A clear N1 P2 onset response and $N1^1$ and $P2^1$ change response can be seen.



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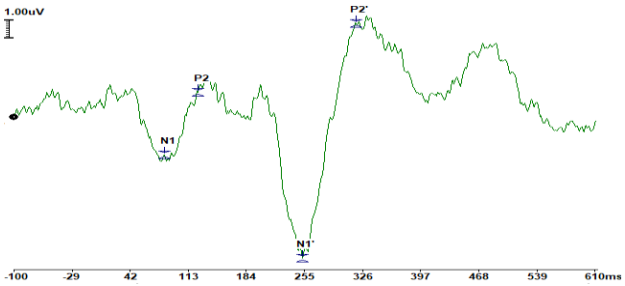

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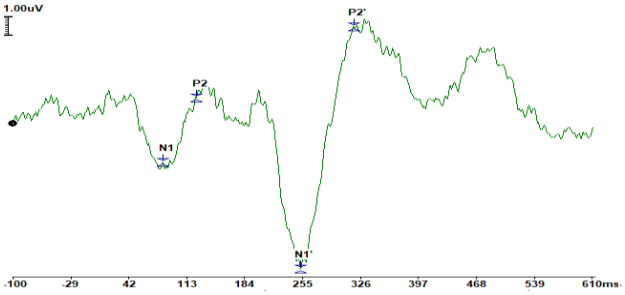


(c)

Figure 4.1: (a), (b), (c) Depict the waveforms of ACC for speech stimulus /sa/ in normal hearing individuals

4.2.2 Non-speech stimuli

White noise followed by a 1kHz tone elicited a change complex in all 20 normal hearing subjects. Martin and Boothroyd (1999) reported the presence of acoustic change complex in 10 normal hearing individuals and the stimulus used being noise followed by tone and tone followed by noise. Table 4.3 and 4.4 depicts the latencies and amplitude of onset and change response in normal hearing individuals for non-speech stimuli.

Table 4.3

Mean and standard deviation of latency for normal hearing subjects for non-speech stimuli

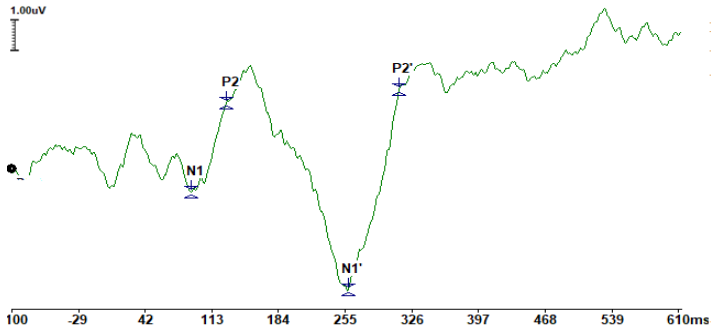
Peaks	Mean latency (ms)	SD for Latency (ms)
N1	110.9	14.4
P2	146.2	20.6
N1[1]	255.1	9.8
P2[1]	302.5	11.4

Table 4.4

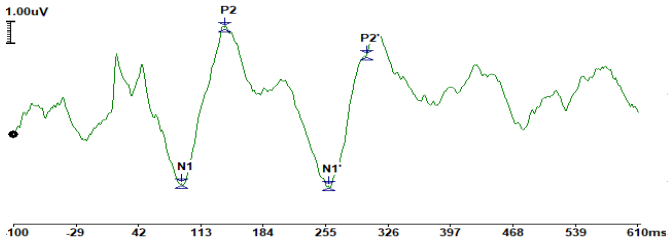
Mean and standard deviation of peak-to-peak amplitude for normal hearing subjects for non-speech stimuli

Peaks	Mean amplitude(μV)	SD for amplitude(μV)
N1P2	2.9	0.9
N1[1]P2[1]	4.1	1.0

In the Figure 4.2 ACC for non-speech stimulus of three individuals (a,b,c) is shown. A clear N1 P2 onset response and $N1^1$ and $P2^1$ change response can be seen.



(a)



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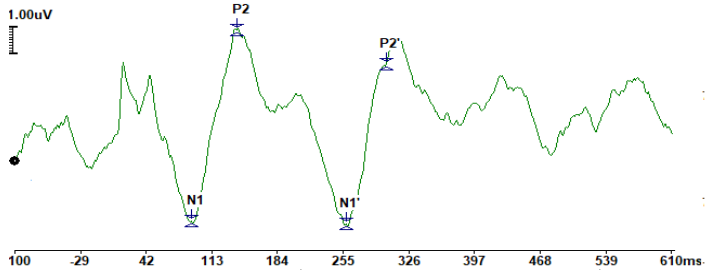


(c)

Figure 4.2: (a), (b), (c) Depicts the waveform of ACC obtained non-speech stimuli in normal hearing individuals

4.2.3 Cortical potentials in ANSD subjects. The current study results shows that acoustic change complex can be obtained in individuals ANSD. In the individuals with ANSD onset/or onset change responses were present for speech and non-speech stimuli respectively. Out of which 20 individuals who had onset responses, 10 individuals had change responses for speech stimuli. Both onset and change responses were seen in 4 individuals and 2 individuals had no response at all. For non-speech stimuli 8 had onset response and 6 had change response. Both onset and change responses were present in 4 and 2 individuals had no response at all. These results indicate that in ANSD the ACC responses varied from being present to absent with some individual's and few individuals with just onset or change responses. As reported in the methods LLR were present in all the individuals. Hence this study points out to the use of complex stimuli to understand cortical encoding of acoustic stimuli in individuals with ANSD.

CAEPs may be present for simple stimuli in individuals with ANSD as it requires less synchronous firing (Kraus et al., 2000; Kumar & Jayaram, 2005; Vanaja and Manjula, 2004; Narne and Vanaja, 2008; Singh & Barman, 2010; Yuvaraj & Mannarukrishnaiah, 2015). The presence or absence of CAEPs may be taken as an indicator of severity of ANSD. Further, the responses of ACC could be more useful in understanding dysynchrony. Tables 4.5 and 4.6 depicts the mean latencies and peak-to-peak amplitude of onset and change responses for speech stimuli in individuals with ANSD. Tables 4.7 and 4.8 depicts the latencies and peak-to-peak amplitude of onset and change responses for speech stimuli in individuals with ANSD

Table 4.5

Mean and standard deviation of latency for ANSD subjects for speech stimuli

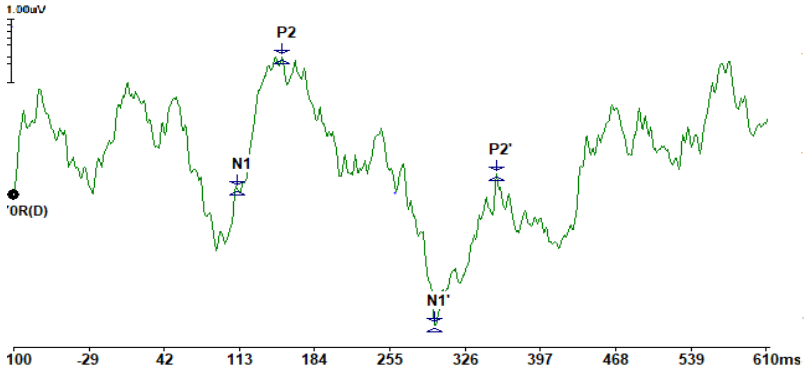
Peaks	Mean latency (ms)	SD for Latency (ms)
N1	113.6	13.9
P2	145.8	22.01
$N1^1$	279.4	32.8
$P2^1$	326.9	39.6

Table 4.6

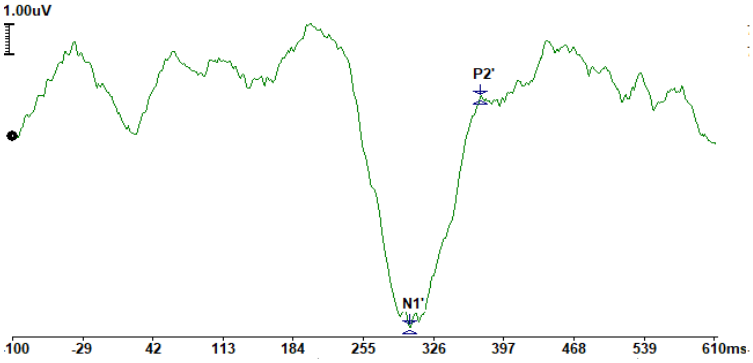
Mean and standard deviation of peak-to-peak amplitude for ANSD subjects for speech stimuli

Peaks	Mean amplitude	SD for amplitude
N1P2	3.1	1.9
$N1^1P2^1$	4.4	1.2

The Figure 4.3 shows ACC for speech stimulus /sa/ in three individuals (a,b,c) with ANSD. In individual (a) and (c) both onset response and change response can be seen and in individual (b) only change response can be seen.



(a)



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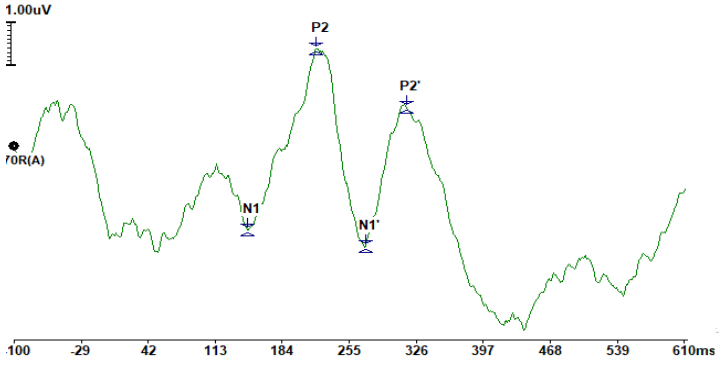


(c)

Figure 4.3: (a), (b), (c) Depicts the waveforms of speech stimuli for ANSD individuals

Table 4.7

Mean and standard deviation of latency for ANSD subjects for non-speech stimuli

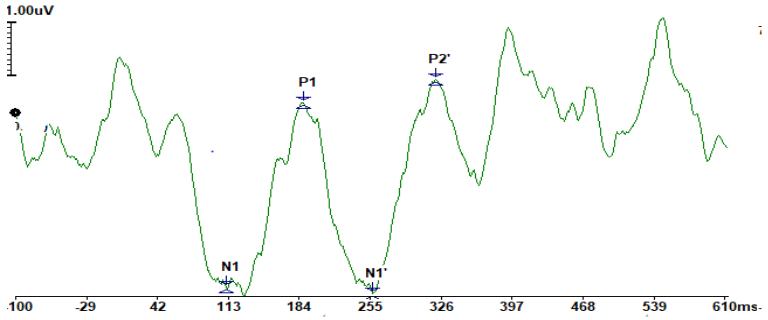
Peaks	Mean latency (ms)	SD for Latency (ms)
N1	122.02	18.02
P2	172.4	15.02
N1[1]	260.3	47.1
P2[1]	316.1	49.7

Table 4.8

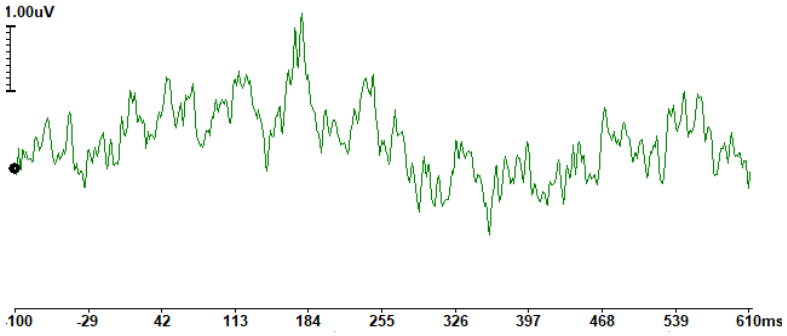
Mean and standard deviation of peak-to-peak amplitude parameter for ANSD subjects for non-speech stimuli

Peaks	Mean amplitude(µV)	SD for amplitude(µV)
N1P2	3.3	1.0
N1'P2'	3.8	1.5

The Figure 4.4 shows ACC for speech stimulus /sa/ in three individuals (a,b,c) with ANSD. In individual (a) both onset response and change response can be seen and in individual (b) both onset and change responses are absent. Whereas in individual (c) only change response is seen.



(a)



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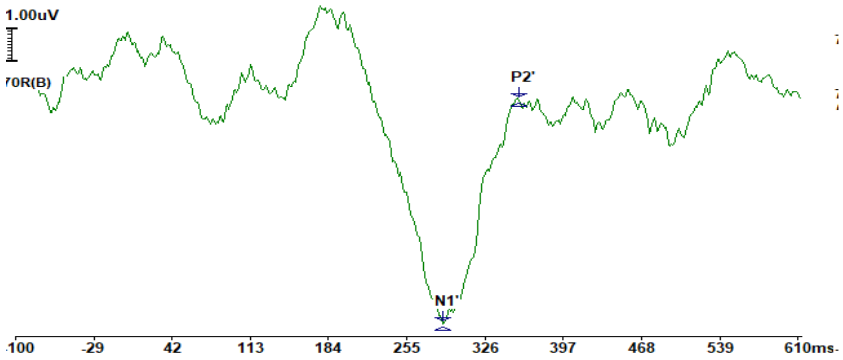

(c)

Figure 4.4 (a), (b), (c) Depicts the waveforms of non-speech stimuli for ANSD individuals. (c) Showing no response

4.3 To Correlation between speech identification scores and evoked potentials in ANSD individuals

Shapiro-Wilk test was done in order to check for normality and the result indicated the data was not normally distributed (P>0.05). Individuals with ANSD were divided into good and poor performers based in their speech identification scores (Mean= 34.85, Median=42.5). Performers above 42.5 were considered as good performers and individuals having scores less than 42.5 were considered as poor performers. Pearson's correlation analysis was done to check if the presence or absence of response to be correlating to good and poor performers. The results showed r = -0.43 (p>0.05). The results showed no correlation with any of the latency or amplitude parameters. Studies have reported both presence and absence of correlation of evoked potentials with speech identification scores.

Chandra and Barman (2009) reported no significant correlation between speech identification scores and evoked potentials for speech stimuli. Narne and Vanaja (2008) observed that the amplitude of N1-P2 complex correlates with word recognition scores in persons with ANSD, suggesting that CAEPs may help in predicting perceptual skills in persons with ANSD. Narne, Barman and Sinha (2011) reported that prolongation in latency and reduction in amplitude of N1 observed in person with ANSD correlate with word recognition score and gap detection threshold but not with audibility. In all the above studies tonal stimuli was used to record the CAEPs. The present study as reported LLR was present for 1 kHz but were not analyzed and correlated with speech scores. Current study used complex stimuli which requires more synchrony for ACC to be elicited. The minimum pre-transition for the stimuli is 80-100 ms (Ganapathy et al, 2013). In case of individuals with auditory neuropathy due to dysynchrony the time required to elicit ACC for rapidly changing complex stimuli may be

affected. This can be studied by increasing the pre-transition duration of the stimulus in ANSD individuals.

In individuals with poor speech identification scores the responses of the initial frication was absent suggesting ACC could be a pointer for individuals with better speech identification scores. There was no correlation between good and poor performers with the presence/absence of the change response for speech stimuli.

Further efforts were made to understand if non-speech stimuli followed any trends which could be compared to good and poor performers and four individuals having both onset and change responses had their speech identification scores ranging from 30-74%. Larger sample is required to assess the same by segregating the groups having different degrees of loss and the variability of speech identification to see a better clarity in the results.

4.4 To compare the cortical encoding of speech and non-speech stimuli in normal hearing individuals and individuals with ANSD

Results comparing speech and non-speech had high variability in individuals with ANSD compared to normal. Out of 20 individuals with ANSD 12 individuals had accounted for the acoustic change complex for speech stimuli and 17 individuals had accounted response for non-speech stimuli, thus ANSD subjects ACC being high variability. Tables 4.9 and 4.10 shows the latency and amplitude between normal hearing subjects and individuals with ANSD for both speech and non-speech stimuli.

Table 4.9

Mean and standard deviation of peak-to-peak amplitude for normal hearing individuals and ANSD subjects for speech stimuli

Peaks	**Normal (Mean)**	**Normal (SD)**	**ANSD (Mean)**	**ANSD (SD)**
N1	115.3	9.4	113.6	13.9
P2	148.4	19.4	145.8	22.01
N1'	263.9	12.4	279.4	32.8
P2'	322.2	18.54	326.9	39.6
N1-P2	3.07	1.0	3.1	1.9
$N1^1P2^1$	3.5	0.93	4.4	1.2

Table 4.10

Mean and standard deviation of peak-to-peak amplitude for normal hearing individuals and ANSD subjects for non-speech stimuli

Peaks	**Normal (Mean)**	**Normal (SD)**	**ANSD (Mean)**	**ANSD (SD)**
N1	110.9	14.4	122.02	18.02
P2	146.2	20.6	172.4	15.02
N1'	255.1	9.8	260.3	47.1
P2'	302.5	11.4	316.1	38.8
N1P2	2.9	0.9	3.3	1.0
N1'P2'	4.1	1.0	3.8	1.5

The morphology of both speech and non-speech responses in individuals with auditory neuropathy spectrum disorder were rated using a self-rated 5 point scale., 0 being no response and 4 being very good. Out of the 20 individuals with auditory neuropathy for speech stimuli 6 had poor morphology 8 had fair morphology and 6 individuals had no response. For non-speech stimuli 1 had good morphology, 8 had fair morphology, 8 had poor morphology and 4 had no response. These results suggest that individuals with ANSD have poor morphologies. Shuman et al., (2013) reported that ACC showed less mature morphological characteristics than the onset P1-N1-P2 response recorded subjects.

Starr et al (1996) reported reduction in amplitude can be accounted for the reduced neural synchrony. Star el al., (1996) reported the magnitude in decrease of amplitude can be explained by the amount of heterogeneity among individuals with ANSD also the reduction in synchrony which leads to less constructive addition of discharges Speech stimuli being dynamic in nature and refractory period between the /s/ and /a/ having an effect. Martin (2007) reported amplitude changes and related it to refractory effects when there was a change in inter-stimuli interval.

Wunderlich et al. (2006) reported presence of N1 peaks in children when presented at slower rates (0.17-0.25 Hz) reason being N1 being inclined to rate of the stimuli. Concluded saying presence N1 in these subjects was attributed to refractory effects. Therefore, the presence of the heterogeneity in individuals with ANSD would be explained by disrupted refractory periods.

Based on the results as there is no correlation between the speech identification scores and cortical evoked potential in normal hearing individuals and in individuals with ANSD null hypothesis is accepted. Further the second hypothesis that there is no difference between the

results of cortical encoding of speech and non-speech stimuli in normal hearing individuals and in individuals with ANSD the null hypothesis is rejected as the ACC responses were affected in individuals with ANSD.

4.5. Implications:

This study gave a clear understanding that ACC is affected in individuals. Also it was seen that there was cortical responses elicited for simple stimulus. Hence this study shows that use of ACC is a better objective tool to study cortical responses in individuals with ANSD.

4.6. Future implications:

1. ACC can be studied with more control of subject selection criteria. For example; classifying based on degree of hearing level; classifying based on performance. These could help in classifying the degree of dysynchrony and its effect on onset and change responses. Also, inclusion of more number of participants would be helpful.

2. The pre-transition duration of the stimulus can be varied. By increasing the duration, more time is available for the cortical neurons to respond for the change stimulus within the ongoing stimulus.

3. The performance of ANSD individuals for SPIN score can be compared with ACC recorded in presence of background noise.

Chapter 5

Summary and Conclusions

Auditory Neuropathy Spectrum Disorder (ANSD) has been defined as a hearing disorder described by abnormal auditory nerve functioning in presence of normal cochlear receptor hair cell activity (Starr, Picton, Sininger, Hood, & Berlin 1996)

Speech identification scores in this study had a varied range and was affected in the presence of noise when SNR50 was carried out.

The study investigated the Acoustic Change Complex for speech and non-speech stimuli and its correlation to speech identification scores in 20 normal hearing individuals and 20 individuals with auditory neuropathy spectrum disorder.

The results suggested that normal hearing individuals have the ability to encode these changes for both speech and non-speech stimuli and in individuals with auditory neuropathy spectrum disorder it was highly variable. Even though there was no statistically significant correlation between the behavioral and objective tests, the presence of the change complex of the speech stimuli was associated with good speech identification scores. Further, the individuals who had 0% score did not have ACC. There is need for further analysis of ACC in larger group to use ACC as a tool to assess good and poor performers. It was also seen that LLR were present in all the individuals, but the ACC were affected. These results point out that ACC can be used as an objective tool to understand ANSD.

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APPENDIX I

MONOSYLLABLES - Mayadevi (1978)	
LIST I	**LIST II**
mɑ	tʃa
t̪a	da
sa	na
tʃa	ka
ḍa	ba
ta	ra
ra	ga
ṇa	pa
pa	ma
va	va
n̪a	ḍa
dʒa	t̪a
ka	na
la	ḷa
ha	dʒa
ḷa	sa
ga	t̪a
ḍa	ʃa
ja	za
ʃa	la

APPENDIX II

Sl no.	PB WORD LIST IN KANNADA - Yathiraj & Vijayalakshmi (2005)									
1.	ರೈತ	raiṭa	ವರ್ಷ	varṣa	ಕಾರು	ka:ru	ಅಮ್ಮ	amma	ಕತ್ತೆ	kaṭṭe
2.	ಅನ್ನ	anna	ಯಾರು	ja:ru	ದಿವ್ಯ	ḍivja	ಜನ	ʤana	ಮೇಜು	me:ʤu
3.	ಮೊಲ	mola	ದಾನ	ḍa:na	ಆರು	a:ru	ರವಿ	ravi	ನಾಯಿ	na:ji
4.	ಚಾಕು	ʧa:ku	ಶ್ಯಾಂಪೂ	ʃja:mpu	ಪೂರಿ	pu:ri	ತಂದೆ	ṭanḍe	ಬಾಲು	ba:lu
5.	ತುಟಿ	ṭuṭi	ಇಲಿ	ili	ಹದ್ದು	haḍḍu	ರಕ್ತ	rakṭa	ನೀಲಿ	ni:li
6.	ಮೇಕೆ	me:ke	ಚುಕ್ಕಿ	ʧukki	ಸುಷ್ಮ	suṣma	ಸುತ್ತು	suṭṭu	ಗೊಂಬೆ	gombe
7.	ಹಾವು	ha:vu	ಬತ್ತ	baṭṭa	ತಾಯಿ	ṭa:ji	ಯಾವ	ja:va	ಕಾಗೆ	ka:ge
8.	ಕತ್ತು	kaṭṭu	ಮಂಚ	manʧa	ದನ	ḍana	ಚಂದ್ರ	ʧanḍra	ಅದು	aḍu
9.	ಬೀಗ	bi:ga	ಬೆಕ್ಕು	bekku	ಶಾಲು	ʃa:lu	ಯಾಕೆ	ja:ke	ದ್ರಾಕ್ಷಿ	ḍra:kṣi
10.	ಓದು	o:ḍu	ಲೋಟ	lo:ṭa	ಹುಳು	huḷu	ಶಾಲೆ	ʃa:le	ಬ್ಯಾಗು	bja:gu
11.	ಬಳೆ	baḷe	ಬಾಲ	ba:la	ಸೂಜಿ	su:ʤi	ಐದು	aiḍu	ಕಷ್ಟ	kaṣṭa
12.	ಮೂರು	mu:ru	ಜೇಬು	ʤe:bu	ರೊಟ್ಟಿ	roṭṭi	ನದಿ	naḍi	ಪೈಸ	paisa
13.	ರಾಣಿ	ra:ṇi	ಮಂಡಿ	manḍi	ಗೂಬೆ	gu:be	ಉಪ್ಪು	uppu	ಮರ	mara
14.	ದಪ್ಪ	ḍappa	ನೊಣ	noṇa	ಅಕ್ಕ	akka	ಕೃಷ್ಣ	kriṣṇa	ಹೂವು	hu:vu
15.	ದಾರ	ḍa:ra	ಮಳೆ	maḷe	ಏಳು	e:ḷu	ವಾಚು	va:ʧu	ಪಿನ್ನು	pinnu
16.	ಬ್ರಶ್ಶು	braʃʃu	ಠೀವಿ	ṭʰi:vi	ವೀಣೆ	vi:ṇe	ಹೊಟ್ಟೆ	hoṭṭe	ಇಡ್ಲಿ	iḍli
17.	ಹಸು	hasu	ದೀಪ	ḍi:pa	ದಿಂಬು	dimbu	ದೋಣಿ	ḍo:ṇi	ಕೇಳು	ke:ḷu
18.	ಜಡೆ	ʤaḍe	ರವೆ	rave	ವಡೆ	vaḍe	ವಜ್ರ	vaʤra	ಸರ	sara
19.	ನಲ್ಲಿ	nalli	ಮೊಳೆ	moḷe	ಗೋಲಿ	go:li	ವಾಣಿ	va:ṇi	ಪದ	paḍa
20.	ಕಿವಿ	kivi	ರೈಲು	railu	ಹಾಲು	ha:lu	ತಲೆ	ṭale	ದಪ್ಪ	ḍappa