Chapter-2

Review of Literature

REVIEW OF LITERATURE

The review section, to a major extent has focused on the basic concepts of hearing related to the effect of aging on the peripheral and central auditory systems, especially the aspects of temporal processing and the timing effect at the brainstem level, relevant to this study The role of Auditory Evoked Potentials (AEPs) in hearing research with its clinical utility has also been extensively reviewed. Speech Evoked Auditory Brainstem Response (SEABR) potentials, generated from the brainstem level in response to a speech stimulus and mainly used to delineate the brainstem function from that of the cortical speech processing in humans is the most prominent among the AEPS and of utmost relevance to this study. The SEABR has been used as a biological marker of auditory processing in children and adults. The current review has focused on the published articles in various national and international journals, case studies as well as review articles on the aforesaid areas. The major focus is to review relevant research information on SEABR and the brainstem timing changes in younger adults to elderly population over a period of last 20 years in order to effectively answer the core research questions and to justify the need for the study.

2.1 Normal Hearing

Hearing is considered as one of the most important senses in humans. The ability of the auditory system to send information from peripheral auditory centers to the brain is integral for understanding speech and non-speech sounds. The auditory system is primarily divided into peripheral and central auditory systems. Peripheral auditory system consists of structures outside the brainstem viz. external ear, middle ear, inner ear and the cochlear nerve. The external ear provides directional cues and transfers these cues in to the middle ear. The middle ear converts these sound waves into mechanical vibrations. Further, these vibrations are transferred to inner ear. The main structure in the inner ear is cochlea whose role is transforming the mechanical vibrations of the middle ear to the cochlear nerve towards the central auditory pathway. The central portion of the auditory system encompasses all the auditory structures located beyond the cochlear nerve. It consists of nuclei, fibers, tracts and commissures.

The levels in the central auditory pathway are completely interlinked in such a way that any disturbance in any of the areas at any point will lead to difficulty in auditory and speech perception. These problems can arise in both children as well as in adults. Due to the impaired temporal precision in the auditory system, difficulty in speech understanding has been expressed by many individuals', especially old and aging adults. The most pivotal factor linked to acquired hearing loss in adults is age. The most enervating forms of hearing loss reported are reduction in speech discrimination. Various technique and procedures are being used to assess the auditory processing in this group of individuals. The recent development of neuro imaging techniques such as PET, fMRI and auditory evoked potentials (FFR, MMN etc.,) enable the study of auditory signal processing in the central auditory pathway in a more comprehensive manner, especially by focusing on the rate at which the signals are processed. This information is critical in understanding the complex mode of auditory processing in humans

2.2 Auditory processing in humans

The acoustic signal processing capability of the auditory system including speech as well as non-speech sounds are integral for humans in speech understanding which ultimately helps in effective communication. The speed at which it processes makes a huge impact on the auditory system to refine and precisely encode all the signals for better understanding .This is termed as auditory temporal processing or timing aspects of the signal processing at the central auditory system.

Plethora of research on the temporal aspects of human auditory system, majorly using psycho acoustical and psychophysical tests exists. The current review is restricted to the effect of aging in temporal processing. The extensive research on timing aspects in auditory system has paved way for a better understanding of the complex auditory temporal processing in human auditory system; specifically the rate at which the signal processing makes the representation of the auditory image as a whole when it reaches the higher auditory centers in the brain.

Study by *Price and Simon (1984*) revealed that age is an important factor in the decline of temporal processing in older adults, which totally affects their speech processing. The study reported that temporal information was expected to give linguistic distinctions between various sounds such as long vowel versus shorter closure of the incoming signal. Such information was important for integrating the whole information to the higher order centers to the brain. Though certain factors were not addressed clearly in their study, overall, it yielded good information on the effect of age on auditory processing in older adults.

Vaughn and Letwoski (1997) studied the auditory temporal order perception in younger and older adults. They used stimulus with three tone sequences which were presented to both the groups. Interestingly, they observed older adults were severely affected with order identification than discrimination as compared to that of the younger groups. However, the authors failed to connect the effect of complex speech sounds on aging.

Gordon, Salant and Fitzgibbons (1999), examined the age related effect on various temporal manipulation of acoustic signals in the presence of quiet as well as noise. They found strong effect on non-speech measures due to aging as compared with other groups. However, they didn't look beyond the non-speech measures in order to precisely demarcate the effect on speech sounds .Similar line of study has been conducted by *Schneider and Hamstra (1999)* who reported that gap detection measures were severely hampered in older age groups than the younger groups.

Pichora-fuller (2003) researched on the effect of timing in auditory processing in older population by using various psychoacoustic methods. The outcome from various measures of the study enabled the conclusion that there were significant effects on temporal processing decline in older adults even though there were primary interactions with cognitive function of the person. Such research findings have opened up a whole lot of new research areas allowing professions like psychology and other cognition related areas to probe the effect of aging in cognitive aspects as well as temporal aspects.

Another study by *Gordon, Yeni, Fitzgibbons and Barett (2006)* looked at the temporal processing abilities across the life span by using various tests. They found the performance of the older adults to be poorer as compared to that of the middle-aged and younger aged adults.

However, the authors have mainly used the behavioural measures in their study with its pitfalls, limiting its application in clinical population.

Peelle, Trojani, Grossman and Winglfield(2011), studied the effect of aging on the neural system for supporting the speech comprehension. They reported that even a moderate decline in the peripheral auditory acuity would remarkably down regulate the central auditory processing for speech sounds, evident on the measures used for the older population in their study.

*Jafari, Omidvar and Jafarloo (2013),*studied the effect of aging on various temporal processing measures such as time compressed speech test and temporal resolution for words in quiet as well as in the presence of noise. Their results were supportive of the existing literature claims that older adults performed poorly for time compressed tests than their younger counterparts. They concluded that aging had a remarkable effect on the speech processing and temporal resolving abilities which eventually affected the speech perception in older adults.

Humes (2015) reported of an interesting study done on cognitive and sensory processing in middle aged adults by using various psychophysical measures. The study was a comparison with younger and older adults and reported of significant effects in cognitive function and sensory processing in middle aged adults. This study gave additional input to the researchers on the importance of involving the middle aged groups, whenever any such experiment was conducted with older adults and younger adults.

Auditory processing researches have further advanced to link with the hearing loss, temporal processing and cognitive function abilities in older adults. The advances in the audiological measures of both behavioral and psycho acoustical natures have taken the temporal processing research to a newer height. However, one important factor requires to be mentioned on the efficacy of the test materials and the undue importance given to behavioral measures alone to draw inferences. Certain areas of research have mainly followed the same paradigm and the study protocols, which has led to the repetition of same errors, such as subject and stimulus factors which could possibly question the implications of these studies in clinical population.

The advent of new tools in the temporal processing and timing related research and the need for more objective quantification of the test procedures have led to a spurge of AEP studies in clinical research, especially focusing on temporal processing in adults as well as in children. Though the area is relatively new, various labs have initiated research to understand the complex auditory processing through the AEP measurements. Most importantly, the entry of AEPs into these domains has shown a paradigm shift in the auditory processing research from psycho acoustical methods to AEPs: researchers are also more convinced with the quantified responses obtained from the AEPs. However, various challenges need to be addressed through extensive research, such as the stimulus and recording factors in AEPs research. The following section would review the important work done in the areas of AEPs; especially, SEABR.

2.3 Auditory Evoked Potentials

Auditory evoked potentials (AEPs) represent the electrical events generated within the auditory pathway for a repeated, controlled auditory stimulus. The continuous *Electroencephalogram (EEG)* can be recorded by placing electrodes on the surface of scalp. The auditory system response can be subsequently attained by calculating computer average. AEP is a non-invasive method that has been widely used by clinical researchers to detect the thresholds in the difficult to test population, for the site of lesion testing and to study the speech processing in various levels in central auditory pathway. AEP tests have also been used to study the auditory processing of many discrete and neural generating sites along the central auditory pathway from the cochlea to the auditory cerebral cortex. This auditory processing at the brainstem and cortical areas can be studied using AEPs which are divided into various categories based on the latencies. They are cortically generated AEPs (LLR MMN, and P300) and brainstem generated potentials (ABR, FFR and MLR) using speech or non-speech stimuli. Among the various stimuli, non-speech stimuli (click and tone burst) are widely used to study the brainstem responses (*Jewett & Williston, 1971; Sohmer& Pratt & Kinarti, 1977; Maurizi, Altissimi, Ottaviani, Paludetti, & Bambini,1982; Wegner & Dau, 2002).*

The use of various stimuli in AEPs has been an area of research for more than three decades by various labs around the world. Various researchers have used the combination of click and tone burst evoked ABR measurements to estimate pure tone thresholds. They figured that click-evoked ABR thresholds were reasonably predicted at the mean behavioral thresholds of 2 kHz and 4 kHz. However, several cases of hearing loss were underrated while using click elicited ABR at these frequencies. Click-evoked and low-frequency tone burst-evoked ABR threshold measurements were employed as a quick tool to facilitate gathering of vital clinical information for the ends of the audiogram (*Gorga, Johnson, Kaminski, Beauchaine, Garner & Neely, 2006).*

It is perceived that a complex stimulus would be more efficient as against the simple click stimulus to evaluate the effect of aging on the neural encoding of rapidly varying acoustic signals at the sub cortical region of the central auditory system. The complex sounds which have been used to evoke the ABR include, musical sounds, non speech vocalizations and various consonant vowels, vowels alone and syllables alone, as reviewed by *Skoe and Kraus (2010).*Recently, there has been a herculean effort by various researchers with great interest in evaluating the brainstem responses using speech as a stimulus. As a result of this, ABR elicited using synthesized consonant - vowel (CV) syllable /da/has been the most extensively researched brain stem responses to complex stimuli in recent times. The following section would review the existing research done on the SEABR in general and also pertaining to the aging population.

2.4. Speech Evoked Brainstem Response- SEABR

Since its advent in early 70’s by Jewett and Williston, ABR has undergone series of research, both clinically as well technically in order to refine its use in clinical research. However, early 90’s saw a paradigm shift in ABR research due to the application of advanced computer technology which gave confidence to researchers to try and use more complex stimuli in ABR recording rather than traditional clicks and tone burst stimuli. This has led to the use of various stimuli in humans to analyze the fundamental processes involved in the complex signals like speech and music. Several studies advocate that encoding needs imposed on the brainstem by the click and speech stimuli vary considerably. A specific section of child population with learning and literacy impairments have reported defective neural encoding with a normal click evoked brainstem response *(Cunningham, et al, 2001; King, et al, 2002; Wible, et al, 2004, 2005; Banai, et al 2005;Johnson et al., 2005; Russo, et al , 2005; Song, et al, 2006).*

A striking feature was the difference in peak latencies for the complex stimuli that were seen during the initial 10 msec of the response. This portion was presumed to be the most consistent across the stimuli produced in the upper brain stem regions. These evidences, hence underscore the prime neural encoding differences between click and speech stimuli, though they are believed to be generated from similar sites. Furthermore, the frequency-following response (FFR), an important component of the SEABR, has been recorded in adults by using various complex stimuli *(Galbraith Arbagey, Branski, Comerci, & Rector,1995; Krishnan, 1999, 2002),* The FFR is thought to reflect the encoding of the fundamental frequency and harmonic structure of the complex speech stimuli and has midbrain origins as reported by *Galbraith, (1994).* However, it is not sure how the developmental time course of FFR takes place in humans, even though the waveform elicited by the speech signal closely resembled the waveform evoked by a click or a tone burst for the initial part of the speech segment. A complete analysis would reveal much more complex auditory processing information such as phase locking responses which can be studied in detail with remarkable fidelity by using this speech signal *(Kraus &Nicol, 2005; Johnson, et al, 2005).*

It was in early 2000 that SEABR picked up momentum in the clinical research labs across the globe. In 2001, *Cunningham, et al*, studied the cortical and brainstem processing in children with learning difficulties to underline the subconscious speech processing deficit in them. They reported that there is considerable evidence to prove that there is a clear disassociation of the signal processing, especially for complex speech sounds such as voiced stop consonant/da/ at the brainstem level and partially at the cortical level in children. It was believed that these findings have paved the entry of complex speech signal into ABR's clinical research more often than not compared to the early 1990's research activities in ABR related areas.

The auditory brainstem response evoked by a speech signal comprises of transient peaks and sustained portion of the response that comprises the FFR *(fig: 1)* .The response to the transient portion of the speech stimulus /da/ comprises of a positive peak which is recorded after 7 ms post stimulus onset named wave V, homologous to the wave V of click evoked ABR. This is subsequently preceded by a negative trough which is named as wave A and then wave C. In some of the recordings prior to the positive peak wave V response, waves I and III were also observed. Preceding the onset response, peaks D, E and F were termed as the FFR. It is predominantly the neural phase locked response of the speech stimulus, fundamental frequency and the spectral harmonics less than 2kHz.The latency difference between D-E and E-F, thought to be representing the vibration of the vocal folds which correspond to the wave D (22msec), E (31msec) and F (40msec) in response. The offset of the stimulus is recorded at 48ms and termed as wave O.

Kraus & Nicol, (2005), stated that SEABR waveform comprises of responses to the acoustic and the acoustic filter features of the speech syllable. They found that the greater frequency changes between D, E, and F were analogous to the first formant of the stimulus which is approximately 500 Hz and F2, were beyond the phase locking limit of the brainstem. The added advantage of studying the FFR in various populations has made SEABR a prominent tool in assessing the auditory processing in humans, which was hitherto not possible with non-speech stimuli. The FFR does not appear in the transient click-evoked response. The FFR corresponds to the encoding of the fundamental frequency of the stimulus as well as the harmonic structure. Thus, the advantage of SEABR was that it depicts both transient and sustained sections of the stimulus that could be objectively measured at the brainstem region in any age group.

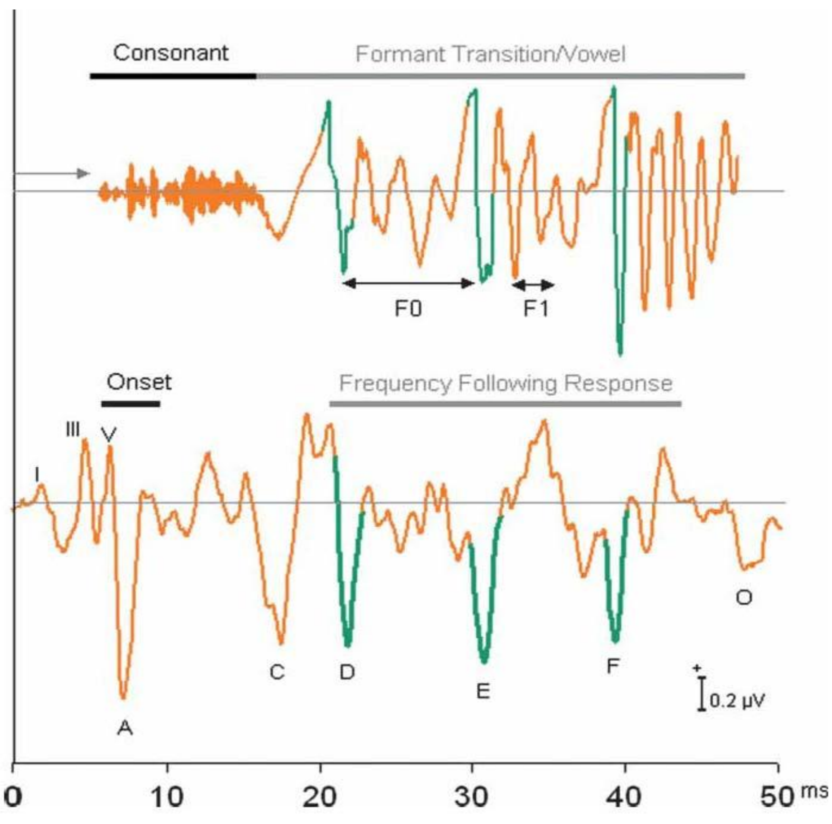

Figure 2.1: Auditory Brainstem Response to Speech Syllable /da/ *(Banai, et al, 2007)*

In the earlier days of SEABR research, many questioned the test retest reliability of the SEABR recording with /da/ stimulus. *Song, et al,(2011)* from Auditory Neuroscience Lab in North Western University, USA, reported that the transient and sustained responses for the SEABR were reliably obtained with high test-retest stability and with very less variability across the subjects. All components of the SEABR were prominent in quiet recordings. They reported that the SEABR recording under background noise disrupted the transient responses; however, the sustained response was more resistant to the effects of noise. The authors concluded that speech evoked brainstem response faithfully reflected many acoustic properties of the speech signal.

To establish SEABR as a reliable procedure in research and clinical practice, *Russo et al (2004)* established a reliable testing procedure and the normative value to quantify brainstem encoding of speech syllables/da/. They measured the SEABR for the syllable /da/ in quiet as well as noise in 38 normal children. Transient peak responses and sustained, periodic frequency-following responses were assessed with various statistical measures. They found that the measures of transient and sustained components of the SEABR were reliably obtained with high test–retest stability They reported that the SEABR provided a mechanism to understand the neural bases of brainstem auditory function and can be used as biological marker for auditory processing (*Johnson et al 2005 et al, Sinha & Basavaraj, 2011)*.

The advances in the technology have led to the incorporation of these complex stimuli into various evoked potential equipment. This has resulted in the proliferation of clinical studies in various clinics and enormous data has been published in pediatric population using SEABR. The major focus of the research was concentrated on the auditory processing deficits in learning disabled children as well specific language impairment groups *(Wibel et al 2005, Banai et al 2007, Chandrashekaran, Hornickel, Skoe, Nicol & Kraus, 2009).*

Khaladar, Kartik and Vanaja (2004) studied the perceptual deficits in sensorineural hearing loss (SNHL) patients using click evoked ABR and the burst portion of the syllable. /t/. They found that C-ABRs latency values were within normal limits while speech burst evoked ABRs depicted abnormal results. This implied that using speech sounds to elicit the ABR offers an opportunity to better differentiate normal speech processing from that of abnormal speech processing. They reiterated that the burst portion wouldn't provide much information regarding the neural coding of the speech stimulus. Thus, brainstem response to vowels as a measure of frequency following response (FFR) can be used to understand the complex signal processing in humans.

There are studies in the literature specifically focusing on the FFR. *Krishnan (1999)* obtained FFRs to three different two-tone approximations of vowels from 10 normal hearing human adults and reported that phase locking mechanisms do play significant role in the neural encoding of speech sounds. The spectrum analysis of the FFRs showed different peaks at frequencies at the first and the second formants across all levels. These peaks are suggestive of the involvement of two distinct populations of neurons in FFR. He reported that these evidences strongly support the importance of scalp recorded FFRs which may be used to evaluate not only the neural encoding of speech sounds but also the complex cochlear nonlinear process.

In continuation with the FFR research, *Krishnan and Parkinson (2000)* investigated the FFR to a rising and a falling tone in eight normal hearing adults. Their results clearly demonstrated that the human FFR does follow the trajectory of the rising and falling aspects of the tones. It also demonstrated that the changes in FFR amplitude to the different tones may be a reflection that the neural phase locking decreases with increasing frequency. The reduction in FFR amplitude for the falling tone indicates that rising tones reflects stronger neural synchronization than that of falling tones. Their results indicated that the FFR can be used to evaluate the neural encoding of complex speech sounds.

The interesting findings from FFR research has made researchers to probe further in to the encoding of pitch at the brainstem level. *Plyler and Krishnan (2001)* investigated the FFR to determine its effect on the time varying second formant transitions in synthetic stop consonant stimuli in people with normal hearing sensitivity and hearing loss individuals. They also probed the impact of hearing loss on the degradation of the neural encoding of speech. Further, they investigated the degraded representation of speech was correlated with reduced identification of consonant sounds in hearing loss individuals. FFRs were obtained from people with normal hearing sensitivity and hearing loss individuals in response to several synthetic stop consonants. Their results demonstrated that the FFR did encode the second formant transition in normal hearing listeners. However, FFR encodings were severely degraded in the hearing impaired listeners.

Krishnan (2002), Krishnan, Xu, Gandour & Cariani,(2004) further investigated the FFR by using English back vowels and reported that the neural phase locking is represented by two distinct groups of neurons which is preserved in FFR. He also studied the effect of language experience on the early pre attentive stages of pitch processing at the brainstem level. From the results of his study, he postulated that there is a possibility of neural plasticity at the brainstem level that is influenced by language exposure which may enhance certain important linguistic cues in the incoming speech signal. These results suggest that the FFR can provide a non-invasive method to evaluate the neural encoding of speech sounds at the brainstem level for both normal hearing and in hearing loss individuals *(Krishnan et al., 2004).*Thus, it can be inferred from the above stated studies that FFR elicited by the speech stimuli can be effectively used as a non-invasive technique to study the brainstem processing of speech in humans.

*Sheetal, Peter and Rajashekhar (2007)*attempted to quantify the brainstem encoding of the speech sound using voiced stop consonant /da/ in 10 adults (18-23 years) and 10 geriatric (45 – 65 years). Both the transient (Peaks V, A, C, and O) and the sustained portions (Peaks D, E, F) of the responses were analyzed in terms of latency and amplitude. Results indicated that the elderly group had longer latencies than the adult group. Among the elderly group, females had shorter latencies than males. Based on this study and previous literature available, they concluded that the neural encoding of speech gets affected at the level of brainstem which eventually affects the perception of speech as the age advances. The study however, raises various questions on the method employed in the data recording procedure as well as the lack of enough samples to justify the findings. However, it was one of the initial attempts to explore the possible clinical application of SEABR in clinical practice.

Johnson et al. (2008) did a similar study by investigating the brainstem encoding of three different voiced stop consonant-vowel syllables (/ga/, /da/, /ba/) in 22 normal learning children. They found that the SEABR responses were changed in a predictable manner for different speech sounds indicating that the acoustic cues to distinguish the speech sounds are presented in neural response timing, evident in the latency changes for the sounds. They concluded that the results of their study could be used to determine how neural representation of speech is disrupted in the clinical population such as in hearing impaired individuals and poor readers, for those of whom the stop consonants pose greater perceptual challenge in various situations.

Rocha, Filippini, Moreira, Neves and Schochat (2010) did similar research in adults to characterize the findings of the ABR performed with speech stimuli in adults with typical development. They too concluded that SEABR can be used as a new tool for understanding the encoding of sound at brainstem level. *Richard, Jeanvoine, Veuillet, Moulin and Thai-Van (2010)*, reviewed the studies focused on the various electrophysiological methods used to assess speech processing in the human brainstem using SEABR. They reported that SEABR has provided greater understanding of sub cortical auditory processing in adults and children with normal hearing and in hearing impaired individuals. Thus, SEABR has demonstrated its importance in clinical research and used as a non-invasive method for assessing the neural encoding of speech. SEABR can also be used for the diagnosis of speech processing deficits in children as well as in older adults and as a tool to assess the rehabilitation outcome in in patients with auditory processing disorders and with amplification use.

2.5 SEABR in clinical population

The popularity of SEABR in understanding the speech processing in humans has gained its application in the early 2000 which evinced enormous interest in understanding the neural representation of speech in children who pose learning difficulties as well as in older adults whose difficulties in understanding speech is due to decline in the temporal processing.

Cunningham et al., (2001) examined a group of children with learning problems whose speech perception skills worsened in the presence of background noise. The aim of their study was to determine whether these difficulties were associated with abnormal encoding of speech at the brainstem and cortical level. Further they examined the benefits at the brainstem level with the acoustic cure enhancements to an impaired auditory system. They measured the behavioral speech perception measures, ABR, FFR and cortical-evoked potentials and compared their responses to that of normal children. Their results indicated that there were abnormalities in the auditory encoding of speech sound at the brainstem and cortical levels in children with learning disabilities; further, SEABR was severely affected when it was recorded in the presence of background noise. More specifically, the study postulated that the neurophysiologic responses presented a different spectral pattern of SEABR measures.

King et al. (2002) recorded auditory brainstem responses in normal children and children with learning problem using the click stimulus and the formant transition portion of the speech syllable /da/. They could not find any latency differences between the normal and learning problem population for click stimulus; however, the responses for syllable /da/ showed latency differences between the two groups.

Wible, et al, (2004) examined whether the human auditory brainstem represents components of speech sounds differently in children with learning problems as compared to the normal hearing children. They studied the stress of rapid stimulation in response to the onset of the speech sound /da/. Wave V–Vn had a significantly longer duration and reduced amplitude. The amplitude of the FFR was poor in children with learning problem children. They concluded that poor representations of various constituents of speech sounds are instrumental for the added difficulties with higher level language processesin these groups of children

Song et al., (2006) did a similar study in the same group of children aiming to explore the possible linkage between the brainstem processing of click and speech signals. They found normal pattern of click ABR and disrupted delayed latency in SEABR. Further probing of auditory processing in children with auditory processing difficulties showed interesting results in the encoding of FFR in various challenging situations. The study also opined on the role of SEABR, which can be used to monitor auditory rehabilitation in children with auditory processing disorders *(Banai, Abrams, & Kraus 2007,Russo, Bradlow, Skoe, Trommer, Nicol, Zecker & Kraus 2008).*

In *2009, Russo, Nicol, Trommer, Zecker and Kraus*, reported interesting findings of SEABR in Autism Spectrum Disorders (ASD) children. They recorded SEABR and click ABR in children with ASD and without ASD and found that the onset responses and FFR were affected in ASD children, though the Click ABRs were within normal latencies. They postulated that the breakdown in complex processing could be the primary reason for the language impairment seen in ASD children; further, it is important to note that these children do pose significant amount of difficulties in understanding speech when presented in the presence of noise. Similar studies have been reported by others on the effect of SEABR on learning disabled and ASD children *(Russo, Hornickel, Nicol, Zecker& Kraus, 2010, Anderson & Kraus 2010, Song, Skoe, Banai, & Kraus, 2011).*

Research related to SEABR has also focused on other group of individuals such as younger adults aiming to explore the neural processing of speech sounds. In *2012, Neha, Ayas and Kanaka*, did a study on the brainstem processing of speech sounds when the stimuli was presented with background noise. They recorded SEABR in three different conditions such as 0dBSNR, + and – 6dBSNR. They found that the amplitude and latency of the SEABR were affected when the signals were presented with noise than that of no noise situation. They postulated that brainstem plays a key role in understanding the elements of speech sounds and that the neural encoding of speech signal is vital for the higher order processing in humans. *Hornickel, et al, (2009)* too reported that understanding and differentiation of various consonants take place at the level of brainstem and the ability of the auditory system to extract the speech in the presence noise was important in the phonological processing, especially in children

Vander Werf and Burns (2011) studied SEABR in younger and older adults to assess the neural precision timing. They reported a significant amount of reduction in transient responses in older adults than that of FFR. Another study done on similar lines in *2014 by Neupane, Gururaj, Mehta, and Sinha* addressed the effect of repetition rate on SEABR in younger and middle aged adults. They used three different repetition rates and found that the latency of wave V was prolonged in middle age groups than that of younger groups. They also reported that encoding of fundamental frequency was affected with increase in repetition rates. However, these studies failed to explain the exact age or the factors that resulted in the trajectory of the temporal processing decline in older adults. In addition, methodological flaws such as not mentioning either middle aged or older group performance can be questioned on the impact of these studies in clinical research.

Anderson, Clark, Yi & Kraus (2011) studied the speech perception in noise in older adults using SEABR. They recruited 28 older adults and behaviorally assessed them with the test named Hearing In Noise Test (HINT) and objectively by using SEABR in quiet and with background noise. They reported that in the quiet condition; the older group had reduced representation of the fundamental frequency of the speech stimulus and overall reductions in response processes were observed. In the background noise conditions, the older group demonstrated greater challenges in neural encoding, resulting in poor neural synchronization. They stated that from the results, there was a considerable amount of evidence to postulate the role played by brainstem processing timing which was clearly evident in the strong relationship between quiet and noise comparisons on SEABR responses.

Anderson, Clark, Schwoch & Kraus (2012) studied the SEABR in older adults. They hypothesized that older adults would show certain timing delays due to aging. They recorded SEBR in younger and older adults. Their results were consistent with the hypothesis that older adults did show delayed SEABRs, especially in response to the rapidly changing formant transition with higher variability in it. In addition to that, they also found that older adults had decreased phase locking capacity at the brainstem level and reduced response magnitudes than younger adults. Taken together, the study results supported the ongoing postulation that older adults will have disruption in temporal precision in the sub cortical encoding of speech sound, attributed for their difficulties in speech perception.

In *2013, Anderson, Clark, Schwoch & Kraus,* studied the interaction of auditory cognitive function in understanding speech in the presence of background noise in older adults. They recruited 120 older adults and studied the structural equation model by evaluating the various contributions of peripheral hearing, central auditory processing, cognitive abilities and their life experiences in probing speech in noise in older adults. They found that there were strong interactions between the central auditory processing and cognition however, didn't find much interaction with hearing. This factor in their structural equation model indicates the need to form a specific treatment plans for patients complaining of difficulty in hearing in the presence of noisy situations, especially persons with mild to moderate sensorineural hearing loss. The outcome of their studies recommended hearing aid manufactures to focus on certain slow phase signal algorithms in order to address the reduced cognitive function in older adults. The same group of authors reported *(Anderson et al 2013),* on the effect of auditory training on improving speech perception in noise in older adults. They used SEABR measure to assess the neural timing improvement after auditory training. They claimed that with auditory training alone, it is possible to improve speech perception in older adults along with amplification. However, it is not sure as to how long one has to undergo auditory training: in addition, the effects of cognitive functions were also not mentioned in their study.

Clinard and Tremblay (2013), reported that aging degrades the ability to encode the simple and complex sounds in the brainstem. They used consonant vowel /da/ and 1000Hz tone burst stimuli in 34 adults and recorded the responses. They reported that the neural encoding of the simple and complex stimuli declined with advancing age. In SEABR recording, the FFR responses were prolonged in older adults; however, the fundamental frequency responses remained intact. They concluded that complex speech stimuli would give more information on how the speech sounds are represented in the older adults and help in understanding the decline in their performances, especially in challenging conditions

Anderson, Parbery-Clark, White-Schwoch, Drehobl, and Kraus, (2013), studied the effect of hearing loss in sub cortical representation of speech cues. They recorded SEABR in normal and hearing impaired, age matched older groups. They found that in the hearing impaired group, there was a considerable amount of changes in the envelope-to-fine structure representation as compared to that of the normal hearing group. These changes underlie the fact that older adults with hearing loss would pose difficulty when they try to understand speech in the presence of background noise. This study also sheds light on the effects of sensorineural hearing loss on central auditory processing of speech in humans.

Bidelman, Villafuerte, Moreno and Alain (2014) studied the age related changes in sub cortical encoding and categorical perception of speech. They recorded SEABR and speech evoked cortical auditory potentials in younger and older adults. The outcome of their study indicated that older adults did show reduced amplitude for brainstem responses and delayed responses for cortical measures. They reported that there is lower interdependence of brainstem and cortical level in aged adults. This, according to them results in the distorted representation of speech at the brainstem level as well as reduced neural synchrony at the cortical level. Taken together, all these aspects emerge as the primary reasons for the decline in speech perception in older adults. This reiterates the efficacy and importance of AEPs, especially of SEABR in understanding the complex speech processing in older adults.

2.6 Conclusion

The discussed review clearly indicates the relevance and use of SEABR in understanding the neural processing of speech at the brainstem level. Studies using SEABR have focused mainly on normal individuals, dyslexics and hearing impaired population. The interest of SEABR research in older population has opened a window to the research community to understand the complex interaction of various factors that are presumed to be relevant in the decline of temporal processing in older adults. Much of the review has focused on selecting only two age groups, inadequate to understand the timing changes in older adults and has also failed to explain the reasons of why particular age groups were not included in their studies. All these concerns question the application of these studies in clinical research and warranted a more precise & robust methodology to assess the timing changes across age groups from younger to middle aged to older adults. By keeping these in mind and to bridge the gap and naive reports in the existing literature on SEABR, the present study was undertaken to address the questions on the SEABR evidence across the age groups from younger to middle aged to older adults.