Review Article

IJCRR
Section: Healthcare
Sci. Journal
Impact Factor
4.016

AUDITORY BRAINSTEM PROCESSING OF COMPLEX SPEECH SOUNDS IN YOUNGER AND OLDER ADULTS USING SEABR - A REVIEW

Muhammed Ayas[1], Rajashekhar B.[2]

[1]Senior Audiologist -University Hospital, Sharjah, United Arab Emirates; [2]Professor & Dean, School of Allied Health Sciences, Manipal University, India.

ABSTRACT

The ability of the human auditory system to process the acoustic information from peripheral auditory centres to the auditory centres in the brain is integral for understanding speech and non speech sounds. Age is a critical factor that most often impairs the temporal processing in human population. Due to the decline in temporal precision in the aging auditory system, difficulty in speech understanding was expressed by many older individuals.Difficulty in discriminating speech was perhaps one of the most critical forms that hearing loss can have in person's life. There were various techniques and procedures used to assess the auditory processing in this group of individuals. In recent times, the focus lies on using Speech Evoked Auditory Brainstem Responses (SEABR) to unravel complex speech processing at the brainstem level in children and adults. This article reviews the various studies done using SEABR to understand the brainstem timing changes in various age groups.

Key Words: Speech evoked auditory brainstem response (SEABR), Temporal processing, Onset responses, Frequency following response

INTRODUCTION

Hearing is considered as one of the most important senses in humans. The ability of the auditory system to process the acoustic information from the peripheral auditory centres to the auditory centres in the brain is integral for understanding speech and non speech sounds. The auditory system is primarily divided into peripheral and central auditory system. The levels in the central auditory pathway are completely interlinked and any disturbance in any of the areas at any point will lead to the difficulty in auditory and speech perception in humans. Due to the impaired temporal precision in the auditory system associated with aging, there were difficulties in speech understanding expressed by many older individuals. Age is a critical factor that is most often associated with acquired hearing loss in the adult population. There were various techniques and procedures used to assess the auditory processing in this group of individuals.The recent developments in auditory evoked potentials and neuro imaging techniques allows one to probe auditory processing in a more comprehensive manner .This was done by focussing primarily on the rate at which the signals were processed. This information was critical in understanding the complex mode of auditory processing in humans. The review was focused largely on the existing studies on auditory processing in humans and the use of SEABR in understanding the complex speech processing at the auditory brainstem level in various age groups.

Auditory processing in aging auditory system

The human auditory systems ability to process acoustic signals such as speech and non-speech sounds are integral in understanding speech in humans. This ultimately helps in effective communication. The speed at which this process occurs makes a huge impact on the auditory system to refine and precisely encode all the signals for the better understanding and was termed temporal processing or timing aspects of the signal processing at the central auditory system.

There is plethora of research that has been done to study the temporal aspects in human auditory system majorly using psycho acoustical and psychophysical tests.

Corresponding Author:
Muhammed Ayas, Senior Audiologist, Audiology Unit-University Hospital, Sharjah, UAE.P .O. Box-72772;
E-mail: mohammed.ayas@uhs.ae

Received: 29.04.2015 **Revised:** 25.05.2015 **Accepted:** 29.06.2015

Gordon-salant, et al (1999), examined the age related effect on various temporal manipulation of acoustic signals in the presence of background noise as well as in the quiet. They found a strong effect of aging on non-speech measures in the old age group compared to other younger groups. *Schnided and Hamstra(1999)*conducted a similar line of study and reported that the gap detection measures were severely hampered in older age groups than that of younger groups. *Pichora-fuller (2003)* did a series of research on the effect of timing in auditory processing in older population by using various psychoacoustic methods. The outcome from various measures reached a conclusion that there were significant effects causing temporal processing decline in older adults even though there were primary interactions with cognitive function of the person. These research findings opened up a whole lot of new research areas, which allowed professions like psychology, and other related areas to start probing the effect of aging in cognitive aspects as well as temporal aspects.

Peelle, et al (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. This was evident from the measures used for the older population in their study.*Jafari,et al (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. The results supported the existing literature that the older adults performed poorly for time-compressed tests than that of the younger groups. They concluded that the aging had a remarkable effect on the speech processing and temporal resolving ability .This eventually affected the speech perception in older adults. *Humes(2015)* reported an interesting study done on cognitive and sensory processing in middle aged adults by using various psychophysical measures. The study was compared with that of younger and older adults and reported that there were significant effects seen in cognitive function and sensory processing in middle-aged adults. This study gives an additional input to the researchers regarding the importance of involving the middle-aged groups whenever any such experiments were conducted with older adults and younger adults.

Speech Evoked Auditory Brainstem Response-SEABR

Since its advent in early 70s by Jewett and Williston, ABR has undergone series of research both clinically as well technically in order to refine its utility in clinical research. However, early 90s saw a paradigm shift in ABR research due to the application of advanced computer technology .This further boosted the confidence of the researchers to use more complex stimulus in ABR recording. It replaced the traditional clicks and tone burst stimulus. This has led to the use of various other stimuli such as speech and music. Various studies have demonstrated that click and speech stimuli processes and create a slightly different encoding at the brainstem level. Mainly children with learning disabilities show an abnormal neural processing of speech sounds even when a normal click ABR was present. (Cunningham et al,2001; Wible, et al, 2005; Song, et al, 2006, Johnson et al 2008).

The main interest was the peak latency difference seen for the Speech stimuli that occurs within the first 10msec. This particular portion of the neural response was thought to be generated within the upper brainstem areas. Therefore, these evidences emphasises the important neural encoding differences between the traditional click and the speech stimuli, though they are believed to be generated from the similar sites. Furthermore, the frequency-following response (FFR), which was an important component of the SEABR, was recorded in adults by using various complex stimuli (Krishnan, 1999, 2002). The FFR is thought to reflect the encoding of the fundamental frequency and harmonic structure of the complex speech stimuli; it also has midbrain origins as reported by *Galbraith, (1994).* However, it is not sure how the developmental time course of FFR takes place in humans. Although the waveform that emerges for the initial response to a speech stimuli was similar to that of click stimulus, a complete analysis would reveal much more complex auditory processing information such as phase locking responses. This can be studied in detail with remarkable fidelity by using this speech signal *(Kraus & Nicol, 2005; Johnson, et al, 2005,).*As as result, SEABR came across as one of the widely used tool in understanding the complex speech processing at the brainstem level in various populations.

DISCUSSION

In early 2000, the SEABR picked its momentum in 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 these children. They reported that there is a considerable amount of 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 in the cortical level for the children. It was believed that these findings have paved the entry of complex speech signals into ABRs clinical research more often than not compared to the early 1990s research activities in ABR related areas.

SEABR is a complex waveform that includes a transient response and sustained responses which includes the FFR. The response for the transient portion of the speech stimulus /da/ includes a positive peak that is recorded after 7 ms post stimulus onset named wave V. This is followed by a negative deflection, which is named wave A and then wave C. Following the onset responses are the peaks named D, E and F and 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 2 kHz. The offset of the stimulus is termed wave O *(Johnson et al 2005).* The FFR reflects the encoding of the fundamental frequency of the stimulus and also harmonic structure of the stimulus. Thus, the advantages of the SEABR was that it can extract both transient and sustained portions of the stimulus which can be measured in any age group at the level of the brainstem. However, many questioned the test retest reliability of the SEABR recording with /da/ stimulus. *Song, et al,(2011)* reported that SEABR measures of transient and sustained components can be reliably recorded with high test-retest stability and with minimal variability across the subjects. The authors concluded that the SEABR faithfully records most of the acoustic components of the desired speech signal.

To establish SEABR as a reliable procedure in research and clinical practice, *Russo et al (2004)* established a reliable testing procedure and normative value to quantify brainstem encoding of speech syllables/da/. They measured the SEABR in quiet and background noise in nearly 38 normal children. They found that the responses to the transient and sustained components of the speech syllables were recorded reliably with good test–retest stability and with minimal variability among the participants. They reported that the brainstem response to speech sounds provides a tool to understand the complex neural processing at the auditory brainstem level. Eventually these responses can be used as a biological marker for auditory processing in human population. (*Johnson et al 2005)*.

The advances in the technology led to the incorporation of these complex stimuli into various evoked potential equipment. This has led to the proliferation of clinical studies in various clinics and enormous data has been published in paediatric population using SEABR. The prime focus of the research was particularly 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 et al 2009). Khaladar, et al (2004)* studied the perceptual deficits in sensorineural hearing loss patients using click evoked ABR and the burst portion of the syllable /t/. Speech burst evoked ABRs were more prolonged in latencies which is suggesting that by using speech sounds one can delineate the normal speech processing versus abnormal speech processing. They reiterated that the burst portion would not give us 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 were studies reported in literature that specifically focussed on the FFR. *Krishnan (1999)* obtained FFRs in 10 normal hearing human adults and reported that phase locking plays a key role in the neural encoding of speech sounds. The analysis of the FFRs data revealed a various peaks for the frequencies equivalent to first and the second formants. These results are pointing towards phase-locked activity among two different groups of neurons in FFR. He also suggested that the FFR can be used to evaluate not only the neural encoding of speech sounds but also auditory processing associated with various non linear cochlear functions. 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 pattern of the acoustical properties of the tones. *Krishnan (2002), Krishnan et al(2004)* further investigated the FFR by using English back vowels and reported that phase locked activity among two different populations of neurons is still preserved in FFR. All these findings suggest that the FFR can provide useful acoustic processing information and helps in evaluating the neural encoding of speech sounds at the brainstem level.

Werf and Burns (2010) studied the SEABR in younger and older adults to assess the neural precision timing. They reported that there was significant reduction in transient responses in older adults than that of FFR. *Neupane et al*. (*2014)* studied 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 were prolonged in the middle age group than that of younger individuals. They also reported that encoding of fundamental frequency was affected with increase in repetition rates. *Anderson, et al (2011)* studied the speech perception in presence of background noise in older adults using SEABR. They recruited 28 older adults and behaviourally assessed them with Hearing in noise test (HINT) and objectively by using SEABR in quiet and background noise. They reported that in the quiet condition the older group had reduced neural representation of the speech stimulus and observed an overall reduction in response analysis. Whereas, in the background noise condition, older group demonstrated more deeper decline in neural encoding resulting in poor neural synchrony. Similar findings were reported by *Chandrasekaran et al (2009), Wong et al (2010)* in groups of learning disabled children and older adults.

Anderson, et al (2012) studied the SEABR in older adults and stated that older adults would show certain timing delays due to aging. They recorded SEABR in younger and older adults. Their results were consistent with the hypothesis that the older adults did show delayed SEABRs, especially in response to the rapidly changing formant transition with greater variability. In addition to that, they also found that the older adults had decreased phase locking and smaller response magnitudes than that of the younger adults. In conclusion, the study results supported the ongoing postulation that older adults will have disruption in temporal precision in the sub cortical encoding of speech sounds, which can be attributed for their difficulties in speech perception. Following year in *2013, Anderson, et al* studied the interaction of auditory cognitive function in understanding speech in the presence of background noise in older adults. They found that there were strong interactions between the central processing and cognition, but not hearing. These factors in their structural equation modelling implies the need to formulate specific treatment plans for patients complaining of hearing-in-noise difficulties especially individuals with mild-to-moderate hearing loss. *Anderson et al 2013* reported another study 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 claim that with auditory training alone, one can help them to improve speech perception in older adults along with the amplification use.

Clinard and Tremblay (2013), reported that aging has its effect on the neural encoding of speech sounds in the brainstem level. They used consonant vowel /da/ and 1000Hz tone burst stimuli in 34 adults and recorded the responses. They reported that the neural representation of the speech sound stimuli decline as the age increases. FFR responses were prolonged in older adults; however the fundamental frequency responses are remained intact. They concluded that complex speech stimuli would give more information on how the speech sounds were represented in the older adults and it helps in understanding the decline in their performances, especially in challenging conditions

Anderson, et al, (2013), studied the effect of hearing loss in sub cortical representation of speech cues. They recorded SEABR in normal and hearing impaired older adults. They found that in the hearing impaired group, the envelope-to-fine structure representation was affected in comparison with that of the normal hearing group. This disruption underlies the fact the older adults with hearing loss have difficulty when trying to understand speech in background noise. This study also shed lights into the understanding of the effects of hearing loss on central auditory processing in humans. *Bidelman, et al (2014)* studied the age related changes in sub cortical encoding and categorical perception of speech. They recorded SEABR and Speech evoked cortical auditory potential in younger and older adults. The results of the study indicate that older adults did show reduced amplitude for brainstem responses and delayed responses for cortical measures. They reported that due to the lower interdependence of the two levels such as brainstem and cortical areas in the central auditory system and the implied lesser neural flexibility in older adults, resulted in the distorted representation of speech at the brainstem level as well as reduced neural redundancy at the cortical level. Taken together, all these aspects constitute the primary reasons for the decline in speech perception in older adults. Once again, it illustrates the efficacy and importance of AEPs, especially SEABR in understanding the complex speech processing in older adults.

CONCLUSION

The above discussed review indicates the use of SEABR in understanding the neural encoding of speech at the level of brainstem in humans. Studies using SEABR have been focussed mainly on normal individuals, dyslexics and hearing-impaired population. The interest in SEABR research in older population has opened a window to the research community for better comprehension of complex interactions of various factors that lead to the decline in temporal processing in older adults. Majority of the studies focused on selecting only two age groups, which was not enough to understand the timing changes in older adults. Also, they failed to describe the reason as to why particular age groups were not included in their studies. This may warrant the need for future studies in specific age groups to understand the complex signal processing in adults. However, the existing work done by various authors in SEABR research was commendable and it would improve the clinical value of SEABR. Furthermore, prospectively SEABR could be employed as an important diagnostic tool in audiology clinical practice

ACKNOWLEDGEMENTS

Authors acknowledge the immense help received from the scholars whose articles are cited and included in the references of this manuscript. The authors are also grateful to authors / editors / publishers of all those articles, journals and books from where the literature for this article has been gathered, reviewed and discussed.

REFERENCES

1. Anderson S, Parbery-Clark A, Yi H, Kraus N. (2011) A neural basis of speech-in-noise perception in older adults. *Ear and Hearing*. 32(6): 750-757.
2. Anderson S, Parbery-Clark A, White-Schwoch T, Kraus N. (2012) Aging affects neural precision of speech encoding. *Journal of Neuroscience*. 32(41):14156 –14164.
3. Anderson S, White-Schwoch T, Parbery-Clark A, Kraus N. (2013) A dynamic auditory-cognitive system supports speech-

in-noise perception in older adults. *Hearing Research*. 300: 18-32.

4. Anderson S, White-Schwoch T, Choi H J, Kraus N. (2013) Training changes processing of speech cues in older adults with hearing loss. *Frontiers in Systems Neuroscience*. doi: 10.3389/fnsys.2013.00097
5. Anderson S, Parbery-Clark A, White-Schwoch T, Drehobl S, Kraus N. (2013) Effects of hearing loss on the subcortical representation of speech cues. *The Journal of the Acoustical Society of America*. 133(5): 3030-3038
6. Banai, K., Abrams, D., & Kraus, N. (2007). Sensory-based learning disability: Insights from brainstem processing of speech sound. *International Journal of Audiology, 46*, 524-532.
7. Bidelman GM, Villafuerte JW, Moreno S, Alain C(2014). Age-related changes in the subcortical-cortical encoding and categorical perception of speech. Neurobiology of Aging.;35(11):2526-2540.
8. Chandrasekaran B, Hornickel J, Skoe E, Nicol T, Kraus N. (2009) Context-dependent encoding in the human auditory brainstem relates to hearing speech in noise: Implications for developmental dyslexia. *Neuron* 64: 311-319.
9. Clinard C G, Tremblay K L.(2013).Aging degrades the neural encoding of simple and complex sounds in the human brainstem. Journal of American Academy of Audiology;24(7):590-599
10. Cunningham J., Nicol T., Zecker S. G., et al. (2001). Neurobiologic responses to speech in noise in children with learning problems: Deficits and strategies for improvement. *Clinical Neurophysiology*, *112*, 758–767.
11. Galbraith, G. C. (1994). Two-channel brainstem frequency-following responses to pure tone
12. and missing fundamental stimuli. *Electronencephalography and Clinical Neurophysiology, 92*, 321-30.
13. Gordon-Salant S, Fitzgibbons PJ. (1999).Profile of auditory temporal processing in older listeners. Journal of Speech Language and Hearing Research.42 (2):300-11.
14. Humes LE. (2015).Age-Related Changes in Cognitive and Sensory Processing: Focus on Middle-Aged Adults. American Journal of Audiology. doi: 10.1044/2015_AJA-14-0063. [Epub ahead of print]
15. Jafari Z, Omidvar S, Jafarloo F (2013). Effects of ageing on speed and temporal resolution of speech stimuli in older adults. Medical Journal of the Islamic Republic of Iran.. 27(4):195-203
16. Johnson, K. L., Nicol, T. G., Kraus, N. (2005). Brain stem response to speech: A biological marker of auditory processing. *Ear and Hearing*, *26*, 424–434.
17. Johnson, K. L., Nicol, T., Zecker, S. G., et al. (2008). Brainstem encoding of voiced consonant–vowel stop syllables. *Clinical Neurophysiology*, *119*, 2623–2635.
18. Khaladar, A. A., Kartik, N., and Vanaja, C.S. (2004). Speech burst and click evoked ABR.*Audiology online.* Retrieved from: http:/ www. Audiology online.com /articles/ article detail .asp?article_ id=1373.
19. Kraus, N., & Nicol, T. (2005). Brainstem origins for cortical 'what' and 'where' pathways in the auditory system. *Trends in Neuroscience*, *28*, 176– 181.
20. Krishnan, A. (1999). Human frequency following responses to two tone approximations of
21. steady state vowels. *Journal of Audiology and Neurootology*, *4*, 95-103.
22. Krishnan, A., & Parkinson, J. (2000). Human frequency following responses: representation
23. of tonal sweeps. *Journal of Audiology and Neurootology, 5*, 312-321.
24. Krishnan, A. (2002). Human frequency-following responses: Representation of steady-state synthetic vowels. *Hearing Research*, *166*:192–201.
25. Krishnan, A., Xu, Y., Gandour, J.T., and Cariani, P. A. (2004). Human frequency following responses: representation of pitch contours in Chinese tones. *Hearing Research, 189*, 1-12
26. Neupane, Gururaj, Mehta, Sinha (2014). Effect of repetition rate on speech evoked auditory brainstem response in younger and middle aged individuals. Audiology. Audiology Research. 4:106
27. Peelle JE, Troiani V, Grossman M, Wingfield A (2011). Hearing loss in older adults affects neural systems supporting speech comprehension. Journal of Neuroscience. 31;31(35):12638-43.
28. Pichora-Fuller MK(2003). Processing speed and timing in aging adults: psychoacoustics, speech perception, and comprehension. International Journal of Audiology.;42 Suppl 1:S59-67.
29. Russo, N., Nicol, T., Musacchia, G., et al. (2004). Brainstem responses to speech syllables. *Clinical Neurophysiology*, *115*, 2021–2030.
30. Sinha SK, Basavaraj V.(2011)Speech evoked auditory brainstem responses: a new tool to study brainstem encoding of speech sounds. Indian Journal of Otolaryngology and Head and Neck Surgery.;62(4):395-399.
31. Song, J. H., Banai, K., Russo, N. M., et al. (2006). On the relationship between speech-and nonspeech-evoked auditory brainstem responses. *Audiology and Neurootology*, *11*, 233–241.
32. Song J, Skoe E, Banai K, Kraus N. (2011) Perception of speech in noise: Neural correlates. *Journal of Cognitive Neuroscience*. 23(9): 2268–2279.
33. Werff K and Burns K.S.(2011).Brain Stem Responses to Speech in Younger and Older Adults. *Ear & Hearing* 2010;31
34. Wible B., Nicol, T., Kraus, N. (2005). Correlation between brainstem and cortical auditory processes in normal and language-impaired children. *Brain*, *128*, 417–423.
35. Wong P.C, Ettlinger M, Sheppard J.P, Gunasekera S.M, et al (2010). Neuroanatomical characteristics and speech perception in noise in older adults,. *Ear and Hearing Vol 31, 4,* 471-479.