BRAINSTEM ENCODING OF SPEECH SOUND IN INDIVIDUALS WHO PRACTICE MEDITATION

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CERTIFICATE

This is to certify that this dissertation entitled **"Brainstem encoding of speech sound in individuals who practice meditation"** is a bonafide work submitted in part fulfillment for degree of Master of Science (Audiology) of the student Registration Number: 15AUD012 This has been carried out under the guidance of faculty of the 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 **“Brainstem encoding of speech sound in individuals who practice meditation”** has been prepared under my supervision and guidance. It is also being certified that this dissertation 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 dissertation entitled **"Brainstem encoding of speech sound in individuals who practice meditation"** is the result of my own study under the guidance of Dr. Sujeet Kumar Sinha, Reader in Audiology, Department of Audiology, All India Institute of Speech and Hearing, Mysore, and has not been submitted earlier to any other University for the award of any other Diploma or Degree.

Mysore **Registration No: 15AUD012**
May, 2017

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Abstract

Meditation is a compound mental practice which leads to several changes both physiologically and psychologically. Hence, altered functioning in the cortical and sub-cortical region could be expected. The aim of the present study was to investigate the encoding of speech at the brainstem in the individuals who practice meditation. Two groups were taken in the study, meditation group had 20 participants who practice meditation since min. of 6 months and another age matched non-meditator group. Speech evoked ABR was recorded for right ears for all 40 individual. FFT analysis of the waveforms were done and latency of wave V, and amplitude of F0, H1 and H2 were noted. Since the distribution of data was non-normal, Mann- Whitney test was done to compare the responses from both the groups. Results showed that amplitude of F0 was significantly higher in the meditation group than non-meditators. However, there was no such significant difference in latency of wave V and amplitude of H1 and H2. Increase in amplitude of F0 was also significantly correlated to the duration of the meditators. But no such correlations was seen with other speech evoked response parameters with age of the meditators or mean MAAS scores. Since, cerebral cortex is plastic it can be expected that cortical structures modulate the functioning of brainstem too. Hence, enhancement of amplitude of fundamental frequency in meditators than others. Meditation leads to alter the functioning of encoding of speech sounds in individuals who practice meditation, and can lead to offset of age related speech perception deterioration.

Chapter 1

Introduction

Meditation is a compound mental task. ‘Thoughtless awareness’ which means that meditation is a state of awareness and alertness but without thoughts. Researchers states that if we remove all thoughts, all imagination and all that which is virtually happening from our consciousness, then only consciousness will remain and this is the form of pure consciousness which can be termed as meditation (Singh & Narang, 2014). Meditation can also be referred as to a number of different practices in which a person practice or trains their mind to induces an inward focus (Lutz, Brefczynski-Lewis, Johnstone, & Davidson, 2008).

People who practice meditation experience changes in cognition, sensory perception, hormonal effects and autonomic activities within themselves (Newberg & Iversen, 2003). Meditative techniques have been developed, trialled and refined over hundreds of generations with the specific intention of developing a method by which the person can regularly attain a state of mental peace and tranquility, that is relief from stress (Manocha, 2000). There are three approaches towards meditation, namely concentrative practice, mindfulness practice and guided practice (Kristeller, 1999).

Whereas, major meditational forms include transcendental meditation, Buddhists, Zen, Yoga, Vipassana, Brahmakumari, Mindfulness-based stress reduction (MBSR) etc. (S. Deepeshwar, Vinchurkar, Visweswaraiah, & Nagendra, 2014). Another form of meditation is ‘Sahaj Samadhi Meditation’ which is a concentrative form of meditation (Srinivasan & Baijal, 2007). Here, ‘Sahaj’ means ‘effortless’ and ‘Samadhi’ means silent state of awareness at thought processing level. This is a mantra-based meditation, where a sacred mantra or word has to be silently repeated.

Longitudinal studies on meditation practitioners have shown functional brain changes associated with generalized improvements in cognition and psychological well-being (Saggar et al., 2012).

There exists an ample amount of research on effects of mediation on various physiological and psychological changes. The changes can be an outcome of either short-term meditational changes or long-term effects. Long term mediation practitioners have showed pronounced structural connectivity in them, as in when compared to controls, throughout the entire brain within major projection pathways, commissural pathways, and association pathway (Luders, Clark, Narr, & Toga, 2011). And even, short term mediation produces demonstrable effects on brain and immune function (Davidson et al., 2003). In a study, both long term and short term meditators showed higher vital capacity, tidal volume, breath holding capacity, lower blood pressure levels, and lower serum cholesterol level than non-meditators. Hence, concluding that effect of meditation showed significant improvement in respiratory functions, cardiovascular parameters and lipid profile (Vyas & Dikshit, 2002).

Behaviorally too meditation has shown to have influence on perception, attention and cognition (D. Brown, Forte, & Dysart, 1984). Hence, some effect of meditation on auditory system can also be suspected. Several studies have demonstrated enhancement in auditory functions too in meditators when compared to the non-meditators. In one of the comparative study by Kumar, Sangamanatha, and Vikas (2013), a group of 30 meditators (aged 50-65 years) observed to have had higher performance in speech perception task and temporal tasks such as duration discrimination, modulation detection, and backward masking and duration pattern tests. However, meditators and non-meditators did not vary on certain other temporal tasks such as gap detection test.

Not only psycho-acoustical tests but improvement has also been observed in amplitude and latencies of the peaks in electrophysiological tests also. Assessment of effects of meditation on audition and auditory related potentials revealed a habituation to startling responses, while assessing the startle reflex through electromyography (EMG) using an acoustic signal, (Antonova, Chadwick, & Kumari, 2015). However, most changes have been studied in mid latency (auditory) and late latency auditory evoked potentials in individuals who practice meditation. Some studies reveals that there is an increase in Na-Pa amplitude in meditators when compared to the non-meditators (Panjwani et al., 2000; Singh & Telles, 2015). It has also been reported that amplitude of N1 is significantly higher (Becker & Shapiro, 1981), and P2 latency was reduced in the meditator group when compared to non-meditators. In another study, Telles, Deepeshwar, Naveen, and Pailoor (2015), reported that, meditator group had higher amplitude for P1, P2, and N2 peaks when evoked with clicks. Also, Cahn and Polich (2009), observed that in the presence of a distractor tone, P3a of the distractor tone was found to have reduced amplitude in the individuals who practice meditation. Pre attentive perceptual processes, were also found to be higher in the persons who practice meditation. This was established objectively using mismatch negativity paradigm (Srinivasan & Baijal, 2007).

1.1 Need for the present study

i. Speech evoked ABR is a recent tool to study the encoding of speech sound at the level of brainstem (Sinha & Basavaraj, 2010). The first component of speech evoked ABR (wave V) is analogues to the wave V of the click evoked ABR. The speech evoked ABR has been widely used to study the brainstem encoding of the speech sounds in children with dyslexia (Chandrasekaran, Hornickel, Skoe, Nicol, & Kraus, 2009), children with autism (Nicole Russo, Nicol, Trommer, Zecker, & Kraus, 2009), individuals with presbycusis (Anderson, Parbery-Clark, White-Schwoch, & Kraus, 2012a), in children with language based learning problem (Wible, Nicol, & Kraus, 2005) etc. There is a dearth of information of encoding of the speech sounds at the brainstem in meditators.

ii. It is established that brainstem auditory responses does not gets affected by the state of attention (T. Picton & Hillyard, 1974). However, there can be a possible interaction between stimulus and auditory brainstem responses. For example, McEvoy, Frumkin, and Harkins (1980) reported that peak latencies as well as inter-wave latencies of the auditory brainstem responses were same in meditators as well as non-meditators. However, the authors also reported that at low intensities (40-50 dB) latency of the wave V increased following meditations but at higher intensity the latency was significantly reduced. Liu, Cui, Li, and Huang (1990) also reported an enhancement of brainstem auditory evoked potentials in meditators compared to the non-meditators. However, another comparative study by Panjwani et al. (2000) reported no difference in latency or the amplitude parameters of ABR between meditators and non-meditators. Thus, there are equivocal findings regarding the auditory brainstem responses in meditators. Also, the above mentioned studies have utilized a non-speech stimulus to elicit the auditory brainstem responses. The non-speech stimulus does not reflect the encoding of speech stimulus at the brainstem and the findings could be different for two stimulus in different populations.

iii. It has been reported that cerebral cortex is actively involved in meditation (Lazar et al., 2005). Hence, one may expect cortico-fugal pathway from cortical centres modulating the sub cortical structures and bringing the change at the brainstem.

Hence, we may expect cortico-fugal pathway from cortical centres modulating the sub cortical structures and bringing the change at the brainstem. Similar modulations of the brainstem responses has been studied recently by Parbery-Clark, Strait, Anderson, Hittner, and Kraus (2011) and have reported that the brainstem encoding of speech is better in musicians as compared to the non-musicians. This suggests a possible plasticity of the brainstem structures in musicians. However, there is no such information present in meditators. Therefore, there arises a need to study the brainstem encoding of the speech sounds in meditators.

1.2 Aim of the study

The aim of the study is to investigate the encoding of speech at the brainstem in the meditators.

1.3 Objective of the study

- To find out the difference in speech encoding among individuals who meditate than to those who do not practice meditation.
- To find out a correlation between the duration of meditation and the brainstem encoding of speech sounds.

Chapter 2

Review of Literature

The human soundscape is characterized by complex sounds with rich harmonic structures, dynamic amplitude modulations, and rapid spectral-temporal fluctuations. However, clicks and tone pips cannot define the neural encoding of complex sounds which we actually hear in natural environment (e.g., speech and music, non-speech vocal sounds, and environmental sounds). Moreover, complex sounds include both sustained and transient features, even though, the response to a complex sound is not necessarily predictable from the response to click and tones (Palmer & Shamma, 2004).

Meditation is a cognitive practice directed at fixing the fluctuations of the mind (Bærentsen et al., 2010). There are evidences to show the alteration in brain regions of meditators that is thicker cortices, more brain tissue, increased grey matter density etc. which invariably can lead to increased plasticity ((Hölzel et al., 2011; Hölzel et al., 2007; Lazar et al., 2005; Luders, Toga, Lepore, & Gaser, 2009; Pagnoni & Cekic, 2007). Hence, it’s various effects on various auditory functions too (Cahn & Polich, 2009; S Deepeshwar & Telles, 2013; McEvoy et al., 1980; Telles et al., 2015).

2.1 Auditory plasticity

It has been already established that training induces plasticity in humans and as well as in animals (Shinn-Cunningham, 2001). Many studies have shown the reorganizational effect of cortical structures and sub cortical structures after any form of long term practice. To modify cortical organization as a function of training, music has also been reported in literature as an effective training procedure.

Both behavioural and electrophysiological studies have shown that auditory cortex is capable of reorganization as a function of experience (K. Tremblay, Kraus, Carrell, & McGee, 1997). Studies have shown that the speech- sound training can induce changes in the neural activity at the cortical level. These altered neural activities can be observed using far field electrophysiological recordings (Kraus et al., 1995; Näätänen, Schröger, Karakas, Tervaniemi, & Paavilainen, 1993; K. Tremblay et al., 1997).

K. L. Tremblay and Kraus (2002) Recorded the acoustic late latency responses in 7 normal-hearing young adults and they were trained to identify two synthetic speech variants of the syllable /ba/. As subjects learned to correctly identify the two stimuli, changes in P1, N1, and P2 amplitudes were observed. These results indicate that training-related changes in neural activity are reflected in far-field aggregate neural responses and that distinct patterns of neural change, perhaps reflecting hemispheric specialization, likely represent different aspects of auditory function.

Gottselig, Brandeis, Hofer-Tinguely, Borbély, and Achermann (2004) Investigated learning-related changes through mismatch negativity (MMN), a neurophysiological response correlated with auditory discrimination ability. 32 Participants underwent two MMN recordings. Stimuli were a standard (probability = 85%) and two deviant (probability = 7.5% each for high [HD] and low [LD]) eight-tone sequences that differed in the frequency of one tone. Between recordings, subjects practiced discriminating the HD or LD from the standard for 6 min. The amplitude of the Low Deviant MMN increased significantly across recordings in both groups, whereas the amplitude of the High Deviant MMN did not. Thus, practicing either discrimination increased the MMN for the easier discrimination. Learning and changes in the LD MMN amplitude were highly correlated. Consistent with prior studies of auditory plasticity in animals and humans, tone sequence learning induced rapid neurophysiological plasticity in the human central auditory system.

Research studies have indicated plasticity in musicians. It has been reported that musicians have earlier latencies and larger amplitude for brainstem responses to both speech and non-speech stimuli (Musacchia, Strait, & Kraus, 2008). FFR analysis showed statistically enhanced F0 in musicians was seen when compared to the non-musicians. However such effect was not seen for harmonics. The results also indicated that intensive musical practice and exposure was positively correlated to the strength of pitch encoding in brainstem (Musacchia, Sams, Skoe, & Kraus, 2007). The effects of music training in relation to brain plasticity is extensively under research. Evidences from the neuroscience research has shown that music training leads to changes throughout the auditory system that facilitates musicians for listening challenges beyond music processing (Kraus & Chandrasekaran, 2010).

Another way to study the auditory plasticity due to musical training by Slater et al. (2015) was to conduct a longitudinal study on musicians. They followed a cohort of elementary school children for 2 years, and assessed their ability to perceive speech in noise before and after musical training. After the initial assessment, participants were randomly assigned to one of two groups: one group began music training right away and completed 2 years of training, while the second group waited a year and then received 1 year of music training. Outcomes provide the first longitudinal evidence that speech-in-noise perception improves after 2 years of group music training.

Not only in plasticity, has long term training like music had other beneficial effects too. Parbery-Clark, Skoe, and Kraus (2009) Conducted a study in which Musicians were found to have a more robust subcortical representation of the acoustic stimulus in the presence of noise. The findings suggested that musical experience limits the negative effects of competing background noise, thereby providing the first biological evidence for musicians' perceptual advantage for speech-in-noise.

Also, it offsets the aging related degradation in auditory system. In another study by Parbery-Clark, Anderson, Hittner, and Kraus (2012), they demonstrated the distinct effects of aging and musicianship on the neural mechanisms responsible for encoding the different components of a stimulus. Specifically, their findings indicate that aging negatively impacts the encoding of noise bursts (i.e. onset) and transient frequency sweeps (i.e. formant transition) but not stable frequency components (i.e. vowel). It's been also shown that although musicians and non-musicians experience age-related delays in onset timing, which is the most vulnerable portion of the speech-evoked auditory brainstem response, musical experience wave offs that effect of aging on the neural encoding of the formant transition.

2.2 Speech ABR in different population

There have been many studies done to study the encoding pattern of speech in the brainstem. The assessment tool is known as Speech evoked auditory brainstem responses, which reflects the neural encoding of speech in the auditory pathway. It has been administered in various populations to study the variant mechanism, if any.

Aging

Many studies have reported different findings in audition related tasks and electrophysiological auditory evoked studies in older individuals. Among which the neural encoding of speech sound in older individuals were reported to be having delayed ABRs, especially in response to the rapidly changing formant transition, and greater response variability. It was also found that older adults had decreased phase locking and smaller response magnitudes than younger adults. Hence, loss of temporal precision in the subcortical encoding of speech sounds (Anderson et al., 2012a; Neupane, Gururaj, Mehta, & Sinha, 2014).

Anderson, Parbery-Clark, White-Schwoch, and Kraus (2012b) Observed the age-related reductions in inhibitory neurotransmitter levels and delayed neural recovery can contributed to decreases in the temporal precision of the auditory system. Authors hypothesized that a loss of temporal precision results in subcortical timing delays and decreases in response consistency and magnitude. To assess this hypothesis, they recorded speech evoked ABRs in normal hearing younger (18 –30 years old) and older (60 – 67 years old) adult participants. Older adults had delayed ABRs, especially in response to the rapidly changing formant transition, and greater response variability. Results also revealed that older adults had decreased phase locking and smaller response magnitudes than younger adults and hence, supported the theory that older adults have a loss of temporal precision in the subcortical encoding of sound, which may account, at least in part, for their difficulties with speech perception.

In another study Anderson, Parbery-Clark, Yi, and Kraus (2011) recorded speech evoked ABR in quiet and in noise from the participants who had poor speech-in-noise perception, as result of aging. There were 28 older adults (60-73 years) with normal hearing thresholds, hearing in noise test (HINT) was done on them. They were further divided into 2 groups based on HINT scores. In the quiet condition, the bottom SIN group had reduced neural representation of the F0 of the speech stimulus and an overall reduction in response magnitude. In the noise condition, the bottom SIN group demonstrated greater disruption in noise, reflecting reduction in neural synchrony. The role of brainstem timing is particularly evident in the strong relationship between SIN perception and quiet-to-noise response correlations. All physiologic measures correlated with SIN perception.

However, this loss of precision in neural encoding can be reversed. In various studies effect of training, may it be auditory training or musical training have proven to be a cause of reversal of age related decline in processing of older individuals. It was objectively confirmed using speech ABR, as a pre-post training comparison. (Anderson, White-Schwoch, Parbery-Clark, & Kraus, 2013; Parbery-Clark et al., 2012).

Musicians

Musical training has many beneficiary effects when begun at early life. Changes in brain structure and function during adolescence are well-characterized, and musical training experience modulates adolescent neurodevelopment. In a review literature Strait and Kraus (2014) have stated there are enhanced speech evoked ABR in musicians if compared to age matched non-musicians. This enhancement observed in as young as three years of age to adulthood. School aged children who undergo music training have well differentiated speech evoked ABR for confused speech sounds. However, the ones who does not practice music have no such differentiated responses. Whereas, in adult musicians faster encoding of speech transitions in both noise and quiet in brainstem than non-musicians. Moreover, less detrimental effects of aging in the older aged musicians than similar aged non-musicians (Strait & Kraus, 2014).

To study the enhancement of subcortical and cortical encoding of speech evoked responses in musicians Musacchia et al. (2008) recorded simultaneous brainstem and cortical evoked responses in 14 musician and 12 non-musician subjects. Brainstem response periodicity was related to early cortical response timing across all subjects, and this relationship was stronger in musicians. Peaks of the brainstem response evoked by sound onset and timbre cues were also related to cortical timing. Neurophysiological measures at both levels correlated with musical skill scores across all subjects. Amplitude of fundamental frequency was higher in musicians and neural timings were also early in them. Along with that, brainstem and cortical measures correlated with the age that is more the practice better representation. Hence they implied that the neural representations of pitch, timing and timbre cues and cortical response timing are better encoded inn a coordinated manner, and indicate cortico-fugal modulation of subcortical afferent circuitry.

It is well established that when ears receive the diotic hearing, speech intelligibility in noise is improved. Although musicians have better speech-in-noise perception compared with non-musicians, authors tried to study the extent of binaural processing contributes to this advantage. Hence, Parbery-Clark, Strait, Hittner, and Kraus (2013) recorded speech evoked auditory brainstem responses in 15 young adult musicians and 15 young non-musicians. When presented diotically, musicians demonstrated faster neural timing and greater inter-trial response consistency relative to non-musicians when compared with monoaural condition. Also, musicians demonstrated greater enhancements of all the six peaks from monaural to diotic conditions relative to non-musicians. Furthermore, musicians' enhancements to the diotically presented stimulus correlated with speech-in-noise perception. These data provide evidence for musical training's impact on biological processes and suggest binaural processing as a possible contributes to more proficient hearing in noise.

In difficult to listening situation practice of music leads to better perception than those who haven't practiced music. Hence, Bidelman and Krishnan (2010) examined so as to if musical training helps to overcome the degradative effects of reverberation on subcortical representations of pitch and formant-related harmonic information of speech. They recorded frequency-following responses (FFRs) recorded from 10 adult musicians and 10 adult age matched non-musicians in response to the vowel /i/ in four different levels of reverberation and analyzed based on their spectro-temporal composition. For both groups, reverberation had little effect on the neural encoding of pitch but significantly degraded neural encoding of formant-related harmonics suggesting a differential impact on the source-filter components of speech. However, in quiet and across nearly all reverberation conditions, musicians showed more robust responses than non-musicians. Neurophysiologic results were confirmed behaviourally by comparing brainstem spectral magnitudes with perceptual measures of fundamental (F0) and first formant (F1) frequency difference limens (DLs). For both types of discrimination, musicians obtained DLs which were 2–4 times better than non-musicians.

Musicians have the ability to synch motor movements and auditory beats. To study if this link between two modalities can develop in young children, Carr, Tierney, White-Schwoch, and Kraus (2016) demonstrate a systematic relationship between consistency of beat synchronization and stability of subcortical speech processing in 25 preschoolers (ages 3 and 4 years old). They conducted beat synchronization task and recorded the FFRs. They found out that there existed a systematic relationship between consistency of beat synchronization and phase-locking, specifically at lower frequencies: F0 and its first three harmonics of FFR. They then concluded that beat synchronization might provide a useful window into millisecond-level neural precision for encoding sound in early childhood, when speech processing is especially important for language acquisition and development.

Learning disability

King, Warrier, Hayes, and Kraus (2002) Studied the speech evoked auditory brainstem responses in two groups, normal learning children (NL) and children clinically diagnosed with a learning problem (LP). There were 33 normal and 54 clinical population. Children were in the age range of 8-12 years. Results showed no latency differences between the normal learning children and learning problem population in responses to the click stimuli, although, the syllable /da/ did elicit latency differences between these two groups. Deficits in cortical processing of signals in noise were seen for those LP subjects with delayed brainstem responses to the /da/, but not for LPs with normal brainstem measures. Findings suggested that onset synchrony of brainstem neurons in both groups differed. Children with delayed onset responses also had delay in brainstem FFR. Similarly, studies have done to predict the reading problems at pre-reading age (4yr) and for older children (8-12yrs) too. Significant differences in precision of neural encoding were seen in the children who were at risk of reading problems and those who had reading difficulties. However, those who did not have any such problems had precise neural encoding of speech sound /da/ (White-

Schwoch et al., 2015). This can be attributed to the cognitive deficits seen in children with reading and learning disability.

Studies have shown that the temporal coding of speech correlates well with the reading ability in school age children. However less information is available for children at pre-school age. Hence, White-Schwoch and Kraus (2013) measured auditory brainstem responses to the stop consonants [ba] and [ga] in a cohort of 4- year-old children and assessed their phonological skills. In a typical auditory system, brainstem responses to [ba] and [ga] are out of phase (i.e., differ in time) due to formant frequency differences in the consonant-vowel transitions of the stimuli. The authors found that children who performed worst on the phonological awareness task insufficiently code this difference, revealing a physiologic link between early phonological skills and the neural representation of speech.

One of the studies investigated whether there are differences in the encoding of speech in the brainstem among children with Typical Development (TD), (Central) auditory processing disorder, and Language Impairment (LI). The speech-evoked Auditory Brainstem Response was tested in 57 children (ages 6–12). The three groups were divided like; TD (*n* = 18), (C)APD (*n* = 18) and LI (*n* = 21). Analysis was done on three parameters, they were timing, harmonics, and pitch. A comparative analysis of the responses between the typical development children and children with (C)APD and LI revealed abnormal encoding of the speech acoustic features that are characteristics of speech perception in children with (C)APD and LI, although the two groups differed in their abnormalities. While the children with (C)APD might had a greater difficulty distinguishing stimuli based on timing cues, the children with LI had the additional difficulty of distinguishing speech harmonics, which are important to the identification of speech sounds. The results indicated that there is an inefficient representation of crucial components of speech sounds may contribute to the difficulties with language processing found in children with LI. Furthermore, these findings may indicate that the neural processes mediated by the auditory brainstem differ among children with auditory processing and speech-language disorders (Rocha-Muniz, Befi-Lopes, & Schochat, 2012).

Other Cognitive deficit disorders

Epilepsy results in neurological deterioration, hence, leading to cognitive deficits in children (Holmes & Lenck-Santini, 2006). Since children with cognitive deficits have abnormal encoding of speech in brainstem, similar effect can be hypothesized for children with epilepsy. Therefore, Elkabariti, Khalil, Husein, and Talaat (2014) conducted a study to evaluate whether the speech evoked auditory brainstem responses are also similarly affected in children who get epileptic attacks. 38 children within the age range of 6-12 years with epilepsy and same no. of age and gender matched healthy children were taken for the study. Although the study group disclosed normal click ABR compared to age matched normative values, speech-evoked ABR revealed a delayed waves V and A latencies in both ears. These findings confirmed the hypothesis suggested that there is an abnormal neural encoding of speech at the level of brainstem in children with epilepsy.

Another study aimed to evaluate the severity of cognitive-neurologic decline using objective tests in individuals who experience the concussions. Kraus et al. (2016) Used frequency-following ABR in participants divided into control and concussion group. Both groups had 20 children aged 12 and older. The finding did suggest poor representation of fundamental frequency, and morphologically sluggish neural responses in the individuals who suffer from concussions. However, improvement in Fo representation was seen when the concussion symptoms subside, suggesting a gain in the biological processing. Hence, this study also evidences that neural encoding of speech sounds are plastic in nature, and can be altered.

Autism

In children with autism spectrum disorder, one of the main feature is speech and language impairment. Hence to study the sensory transcription of both filter and source aspects of speech in ASD, speech evoked ABR was used. 21 children with ASD and 18 typically developing children in the age range of 7-13 years participated in the study. The major finding was that children with ASD demonstrated reduced neural synchrony and phase locking to speech cues at the level of the brainstem, despite having normal click-evoked responses. Thus, it was concluded that the sensory transcription of speech in neural encoding is disrupted due to an inability to accurately process both filter cues (peak latencies of V, A, D, E, F) and source cues (F0 related aspects) (Nicole Russo, Nicol, et al., 2009).

Whereas, while comparing typically developing children with children with ASD, it was found that speech evoked ABR in quiet for the children with autism resembled the responses of typically developing children in noise. They established this by analysing responses from 16 children with ASD and 11 typically developing children in the age range of 7-13 years. However, ASD responses showed delayed timing in both conditions of noise and quiet and also reduced amplitudes (quiet) compared to normals. Also, minimal quiet-to-noise response differences were found in children with ASD, presumably because quiet responses were already severely degraded (Nicole Russo, Zecker, Trommer, Chen, & Kraus, 2009).

Another deficiency in children with ASD is reduced prosody as a parameter of the pragmatic (socially contextualized) language impairment. Prosody communicates emotion and intention and is conveyed through acoustic cues such as pitch contour. Thus, in a study the authors made an attempt to examine the subcortical representations of prosodic speech in children with ASD. They using passively evoked brainstem responses to speech syllables with descending and ascending pitch contours, and examined sensory encoding of pitch in 48 children with ASD who had normal intelligence and hearing and were age-matched in the range of 7-13 years with 21 typically developing (TD) control children. Results revealed that some children on the autism spectrum show deficient pitch tracking (evidenced by increased Frequency and Slope Errors and reduced phase locking) compared with TD children. Hence, the findings may have implications for diagnostic and remediation strategies in a subset of children with ASD (NM Russo et al., 2008).

In an another study N. M. Russo, Hornickel, Nicol, Zecker, and Kraus (2010) assessed the impact of auditory training on auditory function in children with ASD. They recorded brainstem and cortical responses to speech sounds in quiet and noise in 5 children after the training. They found out that after the training, few children with ASD had better response timings and few in pitch- tracking, but all of them had better cortical response timings. These results provide an objective indication of the benefit of training on auditory function for some children with ASD.

Other speech and language disorders

In individuals who have stuttering, one of the underlying mechanism hypothesized is auditory processing deficits. In one of the studies, speech evoked auditory brainstem responses has been used as tool to evaluate this auditory perceptual dysfunction, if any. They compared the responses from 25 persons who have stuttering to 25 fluent speakers which served as control group. There were significant group differences for the onset and offset transient peaks. Subjects in stuttering group had longer latencies for the onset and offset peaks relative to the control group. Subjects with stuttering showed a deficient neural timing in the early stages of the auditory pathway consistent with temporal processing deficits and hence it was suggested that their abnormal timing may underlie to their disfluencies (Tahaei, Ashayeri, Pourbakht, & Kamali, 2014).

Phonological disorder is a language impairment labelled for those who inadequately use the adult phonological language rules. A study aiming to determine whether neurophysiological auditory brainstem responses to clicks and repeated speech stimuli differ between typically developing children and children with phonological disorders was conducted. Authors included 18 typically developing children (control group) and in 18 children who were clinically diagnosed with phonological disorders (research group), within the age range of 7-11 years. The data obtained showed that the research group exhibited significantly longer latency responses to click stimuli (waves I, III and V) and speech stimuli wave (V and A) when compared to the control group. Thus, results suggested that there is abnormal encoding of speech sounds, which may be a biological marker of phonological disorders. However, authors also mentioned that these results cannot define the biological origins of phonological problems (Gonçalves, Wertzner, Samelli, & Matas, 2011).

2.3 Meditation and its effects:

a) Effect of meditation on auditory abilities

Both electrophysiological and behavioral methods have been employed to study the effects of meditation on various auditory abilities.

i) Studies on short latency potentials:

The earliest study cited was by McEvoy et al. (1980). They recorded Brainstem auditory evoked potentials (BAEPs) in 5 practitioners of Transcendental Meditation (TM) aged between 25-30 years to determine the effect of meditation, if any. Multiple recordings of ABRs of TM practitioners were taken before and after a period of meditation and were compared with those of age-matched controls. At moderate intensity levels, wave V latencies were more in post meditation recordings. Comparison of slopes and intercepts of stimulus intensity-latency functions indicated a possible effect of meditation on brainstem activity.

In the a study by Panjwani et al. (2000) they have showed differences in mid latency responses in meditators when compared to non-meditators. 32 participants between the age range of 18- 35 years participated in the study. They also studied clicked evoked auditory brainstem potentials and found out that there was no significant changes seen in absolute or inter-peak latencies in both the groups. They argued for this findings saying that meditation practice did not appear to significantly alter neural processing up-to the level of the brainstem and it’s highly localized to cortical structures.

Finally the results of the study by S Deepeshwar and Telles (2013) also showed significant increase in wave V peak latency in random thinking, non-meditative focused thinking and meditative focused thinking sessions. This suggests that during meditation there was no change in processing time of information at the lower brainstem level. It was concluded in the study that meditation is a distinct state in which attention to auditory stimuli improves while the speed of auditory information up to the primary and auditory associated areas appears to be slower.

However, in another study where changes in brainstem and cortical potentials were studied in individuals who were trained in Qi-Gong meditation ranged from 21-54 years. During Qi-Gong meditation, it showed similar results for latencies like in Deepeshwar and Telles (2013) study. But high amplitude of wave I to wave V was noted during meditation. Post meditation these amplitude would drop but did not come as low as pre-meditation state. They also inferred that using this particular meditation technique individuals can modulate the level of neural activity in the cerebral cortex, thalamus, brainstem and periphery too (Liu et al., 1990).

ii) Studies on mid-latency potentials:

In a study by Panjwani et al. (2000) they examined the effect of 'Sahaja yoga' meditation on individuals with idiopathic epilepsy. 32 participants between the age range of 18- 35 years participated in the study. Experimental group practiced meditation for 6 months and control group for the same was taken. They recorded visual contrast sensitivity, auditory brainstem responses, and mid latency responses. Enhanced visual contrast sensitivity and amplitude of Na-Pa complex (MLR) was observed in the experimental group. They supported their findings stating, the changes in the neural process which can be bought by meditation and improved attention in the individuals who practice meditation.

In another study by Subramanya and Telles (2009) They assessed the effect of two yoga-based relaxation techniques on MLAEPs. Out of those two, one was ‘Cyclic meditation’ (CM) which is a technique combining yoga postures with meditation while supine. The MLAEPs were studied before and after the practice of CM compared to an equal duration of supine rest (SR) (another yoga based relaxation technique used in the study) in 47 male volunteers with a mean age of 26.5 +/- 4 years. The Pa wave peak latency and Nb wave peak latency significantly increased following CM compared to before CM. There was a significant increase in the peak amplitude of the Nb wave when compared to baseline for CM. They concluded their findings stating, following CM the latencies of neural generators corresponding to cortical areas is prolonged.

In the study of different auditory evoked potentials on 4 meditation states, the middle latency response showed significantly increased Na and Pa latencies during meditation, which implies that there is, reduced auditory information transmission happening at the level of medial geniculate and primary auditory cortices (S Deepeshwar & Telles, 2013).

iii) *<u>Studies on long latency potentials:</u>*

From the early 1900 research on effects of meditation on auditory system have started. In one of the initial studies, EEG was recorded during, before and after meditation and also during light sleep. In this study there were 8 transcendental meditators and 7 individuals who assisted them in meditation. They were regularly meditating for between 18 months to 6 years. Peaks of n1, p1 and n2 were marked and amplitude were also calculated. Results revealed no significant differences in the responses in meditating condition and baseline and also when compared to responses in light sleep condition (Barwood, Empson, Lister, & Tilley, 1978).

In another study, authors studied long latency auditory evoked potentials (LLAEPs) during meditation. 60 male participants, aged between 18 and 31 years, were assessed in different mental states. They were (a) random thinking, (b) non-meditative focusing, (c) meditative focusing, and (d) meditation. There was significant decrease in the peak latency of the P2 component during and after meditation. The P1, P2, and N2 components showed a significant decrease in peak amplitudes during mental states other than the meditation. Their results suggested that meditation would facilitate the processing of information in the auditory association cortex, whereas the number of neurons were comparatively smaller in random thinking and non-meditative focused thinking (Telles et al., 2015).

Srinivasan and Baijal (2007) Studied the effects of concentrative meditation on pre attentive skills using the mismatch negativity paradigm. Non-meditator control group and meditation group both had 10 participants each, with mean age of 36 and 39 respectively. Twice the MMN was recorded that is at the beginning and after ‘Sudarshana Kriya Yoga’ for meditators similarly before and after relaxation sessions for the non-meditators. Results showed enhanced amplitudes of MMN in meditators. They accounted the higher amplitudes of MMN to the concentrative meditation practice which enhances pre-attentive skills and thus enables better change detection in auditory sensory memory.

Cahn and Polich (2009) Studied meditation and event related P3a potential to draw the line of conclusions of potentials over mental states. 16 participants were in the age range of 24-56 years with minimum practice of 2 years of Vipasana meditation. A three-stimulus auditory oddball series was presented during meditation and a control thought period to elicit event-related brain potentials (ERPs) in the two different mental states. During meditation the P3a amplitude from the distracter was reduced. The meditation induced reduction in P3a amplitude was strongest in participants reporting more hours of daily meditation practice and was not evident in participants reporting drowsiness during their experimental meditative session. The findings suggest that meditation state can decrease the amplitude of neurophysiologic processes that additionally serves attentional engagement elicited by unexpected and distracting stimuli.

S Deepeshwar and Telles (2013) Studied auditory information processing during meditation using early, middle and late latency potentials on 60 male participants aged between 18 to 45 years of age, and then they were assessed in four sessions. The four sessions included various mental status like random thinking, non-meditative focusing, meditative focusing and contemplation. The late latency response result showed that there was a significant decrease in the amplitude of P1, P2 and N2 waves during random thinking and non-meditative focused thinking sessions. However the latency of P2 wave decreased during and after meditation session, which show that auditory transmission is facilitated at the auditory association cortex. The P300 event related potentials showed a change with meditation, which implies that meditation improved the interaction between the frontal lobe, hippocampus and temporal-parietal parts of the brain during the P300 auditory oddball task.

All the studies utilized clicks as stimulus to elicit the brainstem responses and have studied only the onset responses. Since none of the studies have still evaluated the encoding mechanism of speech in brainstem that is sustained responses in the brainstem in individuals who meditates. There is a dearth of information in that area.

b) Effect of meditation on speech perception

Effects of meditation has also been studied using several behavioural measures. Kumar et al. (2013) Assessed the speech perception abilities and temporal processing in the individuals who practice meditation. Temporal processing was evaluated using gap detection in noise, duration pattern tests, duration discrimination, modulation detection, and backward masking. Speech perception was measured in presence of a four-talker babble at −5dB signal to noise ratio and with the vocoded stimuli. Participants of the study were divided into three groups, 30 young adults (Age: 20–30 years), 30 older adults (Age: 50–65 years) who practiced meditation for a period of minimum of five years or more and 51 age matched older adults who did not have any experience of meditation. Results revealed that Meditator group performed significantly better than non-meditator group in all psychophysical and speech perception tasks except in gap detection task. Results of the study also demonstrate that the practice of meditation not only offsets the decline in temporal and speech processing abilities due to aging process but also improves the ability to perceive the modulations compared to young adults.

Another study was done to study whether meditation can lead to improvement in people with severe speech and physical impairments. 7 adults with severe speech and physical impairments (SSPI) which is defined as speech understanding scores less than 25% of the time and/or severely reduced hand function for writing/typing had participated in this study. However, this was an uncontrolled intervention study. Their objective was to describe the development and implementation of a six-week mindfulness meditation intervention and also to identify feasible outcome measures in this population. Exploratory outcome measures were an *n*-back working memory task, the Attention Process Training-II Attention Questionnaire, the Pittsburgh Sleep Quality Index, the Perceived Stress Scale, the Positive and Negative Affect Schedule, and a qualitative feedback survey. However, there were no statistically significant pre–post results in this small sample, yet administration of the measures proved feasible, and qualitative reports were overall positive (Goodrich, Wahbeh, Mooney, Miller, & Oken, 2015).

One of the qualitative study was done aiming at analysing the alterations in perception through tranquility and insight meditation. Semi-structured interviews were held with expert meditators. Participants were 15 monks, 1 nun, and 2 nonmonastic meditator teachers. Four categories of alterations in perception were taken: enhanced quality of perception, comprehension of interdependences in perception processing, cessation of subject/object-based perception, and non-conceptual perception. The findings suggested significant alterations in perception induced by mindfulness practices of meditation. However, it wasn’t concluded whether those alterations were the result of true meditational experiences (Full, Walach, & Trautwein, 2013).

Hence, the studies have shown that there are factors like meditation which influence the auditory functions using both electrophysiological and behavioral tests. Most of which have revealed that meditation leads to better results in the individuals who practice it than the one who don’t practice meditation.

To conclude meditation is a state of mind with which practice can lead to various physiological changes. And these changes can be studied through various objective tests. Speech evoked auditory brainstem responses has proven to be an efficient tool to study the neural encoding of speech in the brainstem. It has used in many studies to find the abnormality in different disordered population. Also speech coding in neural pathway is plastic and can be altered with training.

Chapter 3

Method

The present study was undertaken to study the encoding of speech at the brainstem in individuals who practice meditation. To fulfil the above aim, following method was adopted.

3.1. Research design

The research design utilized for this study was static group comparison which is a pre-experimental group design.

3.2. Participants

Study consisted of two groups. Group-I had 20 adult participants (20 ears) ranging in age from 40-70 years, who followed the same school of meditation. Mindful Attention Awareness Scale (MAAS) which is a standard questionnaire to ensure their efficacy of meditation (Reavley & Pallant, 2009) was administered. Group-II consisted of 20 adult age matched participants (20 ears) who have had no experience in meditation. Same questionnaire were administered in them too, so as to ensure that they have not had any experience in meditation.

3.3 Subject selection criteria

3.2.1. *Group I: Meditation group*

Inclusion criteria for this group included individuals who were practicing 'Sahaj Samadhi meditation' one of the forms of concentrative meditation approach of meditation since a minimum period of 6 months. Only the individuals who got appropriate scoring (≥ 50% scores) in MAAS were included in the study (K. Brown, 2016). All the participants had hearing sensitivity within normal limits (≤ 15 dB HL) for octave frequencies from 250 to 8000 Hz for air conduction and from frequencies 250 to 4000 Hz for bone conduction. There was no middle ear pathology present as revealed by immittance evaluation. None of them had any history of otological problems. Neither the participants had diabetes nor had any associated neurological deficits. Only male participants were the participants for the study, as it has been reported in literature that speech evoked ABR is affected in women in different phases of their menstrual cycle (Prabhu, Banerjee, Anil, & Abdulla, 2016).

3.2.2. *Group II: Non- Meditation group*

Participants of this group were age and gender matched individuals who have never attempt to practise meditation which was confirmed by MAAS scores. All the participants had hearing sensitivity within normal limits (≤ 15 dB HL) for octave frequencies from 250 to 8000 Hz for air conduction and from frequencies 250 to 4000 Hz for bone conduction. There was no middle ear pathology present as revealed by immittance evaluation. None of them had any history of otological problems. Neither the participants had diabetes nor had any associated neurological deficits. Only male participants were the participants for the study.

3.3 Instrumentation

For determining air conduction thresholds, Calibrated GSI-61 (Grason-Stadler Incorporation, Eden Prairie, USA) audiometer with TDH-39 headphone encased in MX-41/AR supra-aural cushion was used. Bone conduction thresholds were estimated using Radio ear B-71 bone vibrator. A calibrated middle ear analyzer, GSI tympstar (Grason-Stadler Incorporation, USA) was used for tympanometry and reflexometry.

Bio-Logic Navigator Pro System (Natus Medical Incorporation, USA) was used to record click-evoked and speech evoked auditory brainstem response.

3.4 Test environment

All the measurement were carried out in an acoustically treated double room situation where the noise levels were as per the guidelines. (ANSI S3.1; 1991).

3.4 Procedure

3.4.1. Pure-tone thresholds were obtained using modified Hughson and Westlake method (Carhart & Jerger, 1959) for air conduction and bone conduction. Frequencies included for tracing air conduction thresholds were 500, 1K, 2K, 4K and 8K Hz. For bone conduction thresholds at 500, 1K, 2K and 4K Hz were traced.

3.4.2. Immittance audiometry was done to rule out middle ear pathology and it was carried out by using 226 Hz probe tone by sweeping the pressure from +200 to -400 dapa. Ipsilateral and contralateral acoustic reflexes thresholds at 500 Hz, 1000 Hz, 2000 Hz, and 4000Hz were recorded for all participants.

3.4.3. Click ABR was done to assess the integrity of brainstem and only if click ABR was present then the participants were subjected to speech abr. Click ABR was recorded at an intensity of 80 dBnHL, using vertical montage, rarefraction polarity, click stimulus of 100µsec., with a repetition rate of 11.1/s. 1500 sweeps were recorded, under the filter setting of low pass as 3000 Hz and high pass as 100 Hz. Analysis window of 25 msec was kept, for recording the responses twice.

3.4.4. Speech evoked auditory brainstem

Speech stimulus for speech ABR

The stimulus used was a 40 ms /da/ synthesized speech syllable produced using KLATT synthesizer (Klatt, 1980) developed first by Cunningham (Cunningham, Nicol, Zecker, Bradlow, & Kraus, 2001). BioMark /da/ has characteristic features containing broad spectral and fast temporal information which gets coded in the neural pathway. The stimulus has fundamental frequency in the range of 103-121 Hz with voicing beginning at 5 ms and an onset noise burst during the first 10 msec. The first formant (F1) rises from 220 to 720 Hz, while the second formant (F2) decreases from 1700 to 1240 Hz over the duration of the stimulus. The third formant (F3) falls slightly from 2580 to 2500 Hz, while the fourth (F4) and fifth formants (F5) remain constant at 3600 and 4500 Hz, respectively (Skoe & Kraus, 2010). The stimulus waveform of /da/ stimulus is given in figure-3.1.

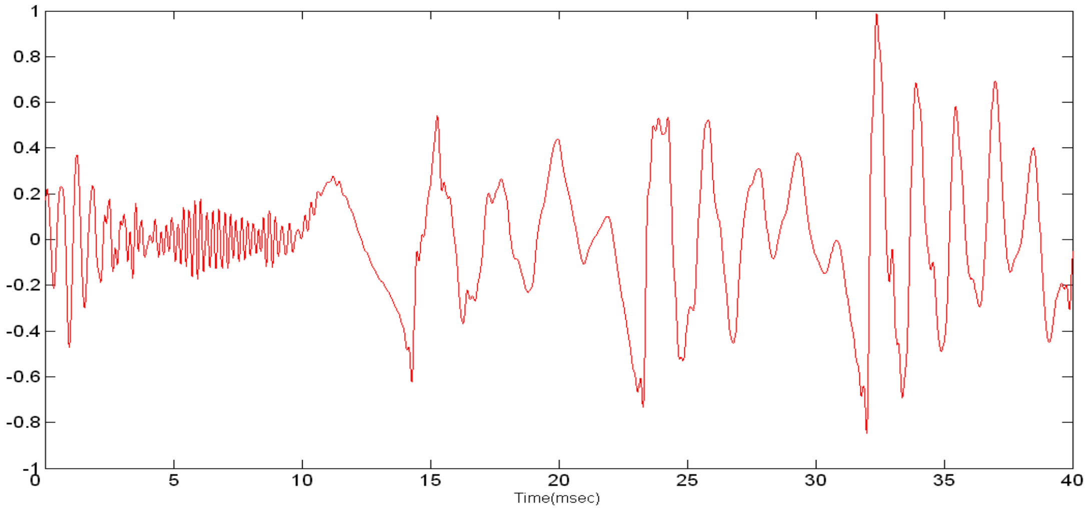

Figure 3.1. Stimulus waveform of /da/ stimulus

Whereas figure 3.2 shows the spectrogram of the speech syllable /da/. Formants of the syllable are also marked.

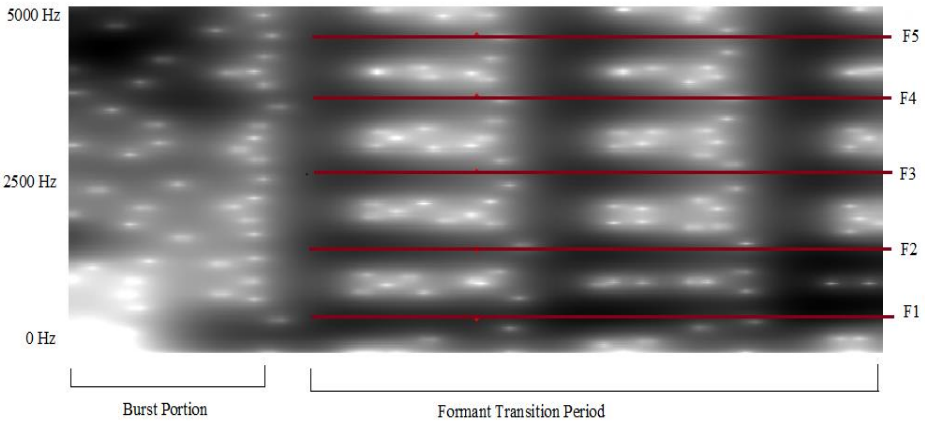

Figure 3.2 Spectrogram of the BioMark /da/ syllable.

Speech ABR recording

Speech evoked ABR were recorded from Fz and mastoid of both ears (A1 & A2). The participant was seated on a reclining chair, in a sound treated room, and was instructed to sleep. The site of electrode placement was prepared with skin NuPrep gel and disc type gold coated electrodes were placed with conduction gel. To keep the electrode in place surgical tape was used. Impedance of each electrode was made sure to be <5 kΩ and inter electrode impedance was within 2 kΩ. Ipsilateral recording was done for all the participants. Transducer used to deliver the stimulus was ER-3A insert ear phones to right ear with a repetition rate of 10.9/s at an intensity of 80dBnHL. Total 1500 Stimulus were presented in an alternating polarity to record speech ABR. The recorded responses were filtered between 100 Hz to 3000 Hz and was analyzed in a 74 msec time window (including 10 msec as a pre-stimulus timing). Speech evoked ABR was recorded twice to ensure the replicability of the responses.

3.5 Evaluation of the data

Speech evoked ABR have two kinds of responses, transient and sustained. Wave V in speech ABR is a response to onset burst of the stimulus and is similar to wave V of click evoked ABR. Fast Fourier Transform is an objective evaluation carried out for the corresponding values of fundamental frequency (f0), formant frequencies and/or harmonics of fundamental frequency. To perform FFT analysis, regions of activity in the fundamental frequency region of speech stimulus i.e. 103-121 Hz, for first harmonic 200-300 Hz and for second harmonic 310-400 Hz were measured for all the waveforms. The entire FFT analysis was done using custom made MATLAB software. The process for this analysis was same as described in studies (Cunningham et al., 2001; Neupane et al., 2014). Figure 3.3 shows the FFT analysis of one of the participants in group 1.

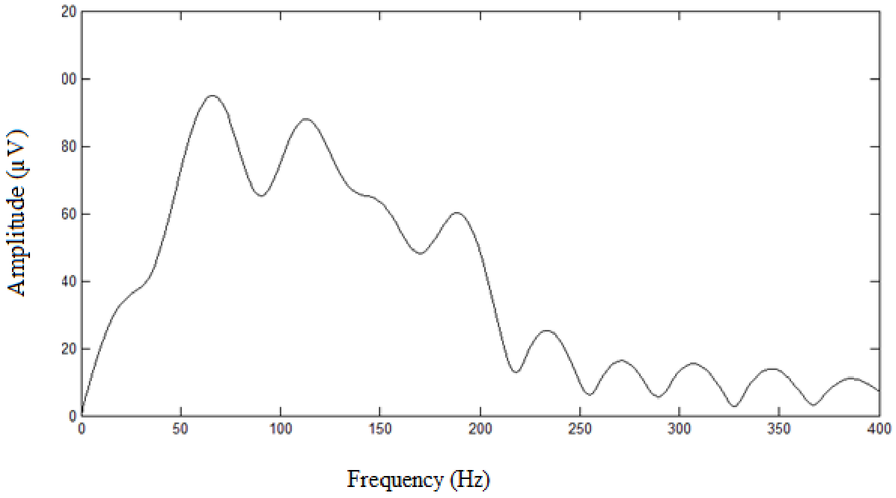

Figure 3.3. spectrum of the FFR responses obtained after FFT.

3.6 Data analysis

i. The mean scores of Mindful Attention Awareness Scale (MAAS) were calculated for all the 20 meditators participating as a part of group 1.

ii. The values of the following parameters of speech evoked ABR were noted for 40 participants together for both the groups.

- Wave V latency marked on the calculated average waveform of the two recorded speech evoked waveforms for all the participants in both the groups.

- Amplitude of fundamental frequency (f0), and harmonics (H1 and H2) were calculated.

3.7 Statistical analysis

After the values of different parameters were recorded from all the 40 participants, the data was analysed. Statistical package for social sciences (SPSS) software version 17.0 was used for the same and also to generate graphical representation for the analysed data. Following statistical analysis were carried out:

- ➢ Descriptive statistics were done to find out mean and standard deviation for latency of peak V and amplitudes of F0, H1 and H2 of speech evoked ABR.

- ➢ Shapiro-Wilks test for normality was carried out for both the groups.

- ➢ Mann- Whitney test was done to compare the latency and amplitude parameteres of across the groups, to see which of the parameter differ significantly from each other.

To study the correlation between speech evoked responses (latency and amplitude) with duration of meditation, age of the participants, and MAAS scores, across all the meditation participants, Spearman’s correlation was used.

Chapter 4

Results

Present study aimed to investigate the brainstem encoding of speech stimulus in individuals who practice meditation. 40 participants participated in the study, which were divided into 2 groups of 20 each based on their experience or no experience in meditation. Table 4.1 tabulates the characteristics of all the 20 participants of the meditation group. It includes the age, thresholds of both ears, and duration of meditation and mean MAAS scores of the all the participants taken under meditation group.

Table 4.1

Age, audiometric thresholds, duration of meditation and MAAS scores of the participants of group 1.

Participants	Age (in years)	Audiometric Thresholds (dBHL)		Duration of Meditation (in months)	Mindful attention awareness scale (MAAS) scores
		R	L		
Participant 1	61	10.00	12.50	15	4.40
Participant 2	66	10.00	13.75	24	3.90
Participant 3	47	7.50	8.75	35	4.40
Participant 4	50	8.75	11.25	24	4.50
Participant 5	56	6.25	10.00	18	4.10
Participant 6	44	13.75	11.25	16	4.00
Participant 7	40	13.75	15.00	6	4.06
Participant 8	47	12.50	10.00	12	4.90
Participant 9	48	15.00	15.00	36	5.40
Participant 10	51	13.75	16.25	32	4.40
Participant 11	52	12.25	15.00	12	4.40
Participant 12	58	11.25	7.25	9	3.90
Participant 13	51	7.25	7.25	32	5.40
Participant 14	50	8.75	7.50	48	4.40
Participant 15	52	11.25	11.25	10	5.30
Participant 16	50	11.25	12.25	12	4.20
Participant 17	47	15.00	11.25	15	4.20
Participant 18	51	12.50	10.00	48	4.80
Participant 19	40	10.00	10.00	44	4.90
Participant 20	62	11.25	11.25	16	4.00

R: right ear, L: left ear

Including both the groups, i.e. the meditator group and non-meditator group, all 40 individuals had presence of speech evoked ABR. The data obtained from speech evoked ABR was then analyzed using Shapiro- Wilk test to check for normality. For most of the data of speech ABR, the test showed value of $p<0.05$ indicating non-normal distribution of the data. Hence, non-parametric test was administered for analysis.

Speech evoked auditory brainstem responses

The latency of peak V and amplitude of fundamental frequency (F0), first harmonic (H1), and second harmonic (H2) of the response for /da/ syllable for both the groups were calculated. The grand averaged speech evoked ABR of meditator group and non-meditator group are given in figure 4.1 and 4.2 respectively.

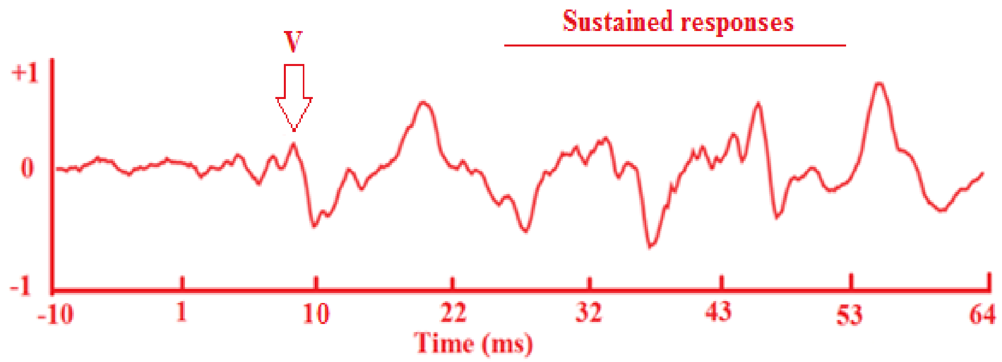

Figure 4.1 The mean average response of meditation group of 20 individuals' right ear.

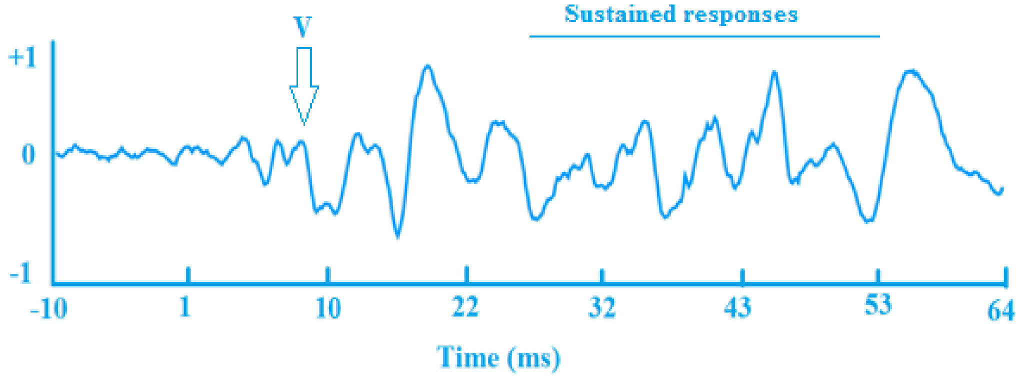

Figure 4.2 The mean average response of non-meditation group of 20 individuals' right ear.

Descriptive statistics was done to find out mean and standard deviation values of amplitude of fundamental frequency (F0), first harmonic (H1), second harmonic (H2) and latency of peak V of speech ABR responses for both the groups. Table 4.2 shows the mean and the standard deviation of the latency of wave V and amplitude of F0, H1 and H2.

Table 4.2

Mean and standard deviation of data of speech ABR responses of both the groups

Parameters	**Group**	**N**	**Mean**	**Standard deviation (SD)**
Amplitude of Fundamental frequency (µV)	**Control**	20	6.99	5.13
	Meditation	20	14.62	10.58
Amplitude of 1st harmonic (µV)	**Control**	20	3.02	1.64
	Meditation	20	6.20	6.89
Amplitude of 2nd harmonic (µV)	**Control**	20	2.11	1.05
	Meditation	20	3.44	3.20
Latency of peak V (msec)	**Control**	20	6.03	0.46
	Meditation	20	6.00	0.25

It can be seen from table 4.2 that the mean amplitude of F0, H1 and H2 are greater in the meditation group than non-meditation group. The mean peak V latency is however, similar in both the groups. Similar results are depicted in the following figures.

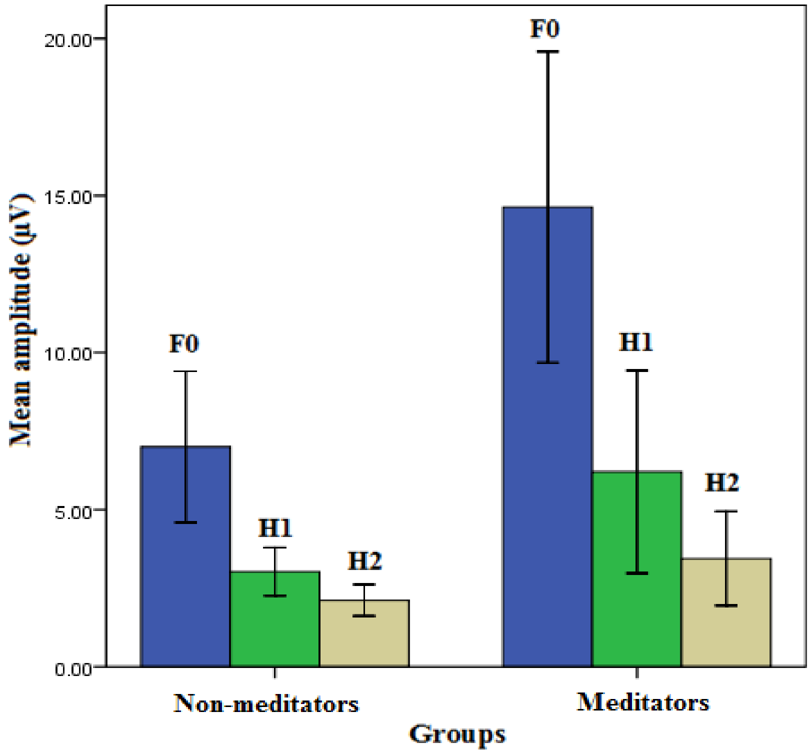

Figure 4.3 The graphical representation of mean and standard deviation of amplitude of F0, H1 and H2 in both the groups.

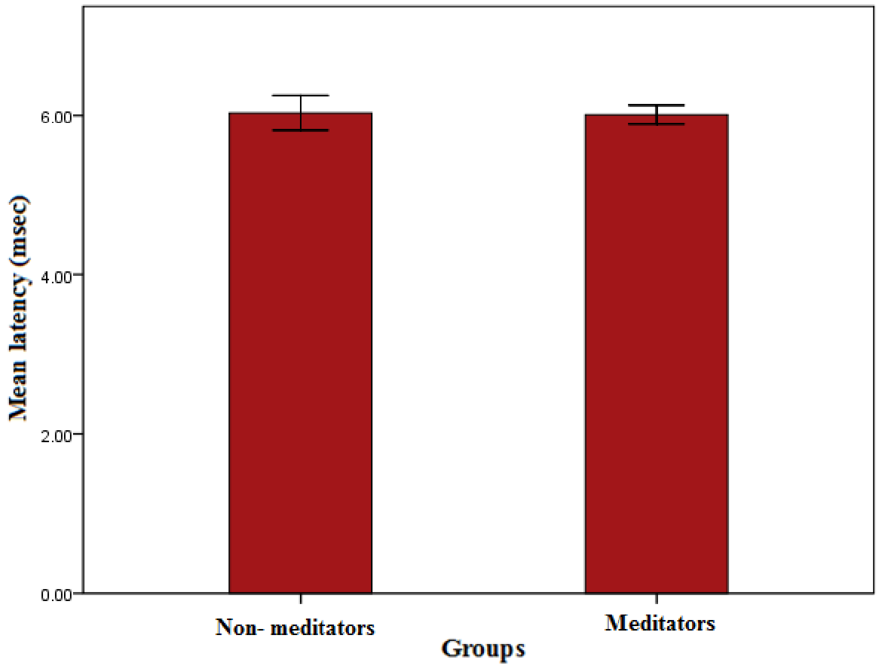

Figure 4.4 The graphical representation of mean and standard deviation of latency of peak V in both the groups.

Comparison of amplitudes of F0, H1, H2 and V peak latency of speech ABR between control and meditation groups.

To compare the amplitudes of fundamental frequency (F0), first harmonic (H1), second harmonic (H2) and V peak latency of the responses for /da/ syllable between both the groups Mann-Whitney U test was administered. Results from Mann-Whitney tests showed that there was a significant difference seen between fundamental frequency of control group and meditation group (*U*=104.5, *p*=0.010). However, no significant difference seen for amplitude of first two harmonics in both the groups under study (*U*=162.5, *p*=0.310), (*U*=154.5, *p*=0.218) respectively. Along with that there was no significant difference seen in the latency of peak V in between both the groups (*U*=198.5, *p*=0.968).

Correlation between duration of meditation and responses of speech evoked ABR (F0, H1, H2 and peak V latency) in meditators

To understand the significant correlation between the duration of meditation with the speech evoked ABR, Spearman’s correlation test was done. Before administrating the Spearman’s correlation test Scatter plots were made to understand the different data distribution between the duration of meditation and speech ABR parameters.

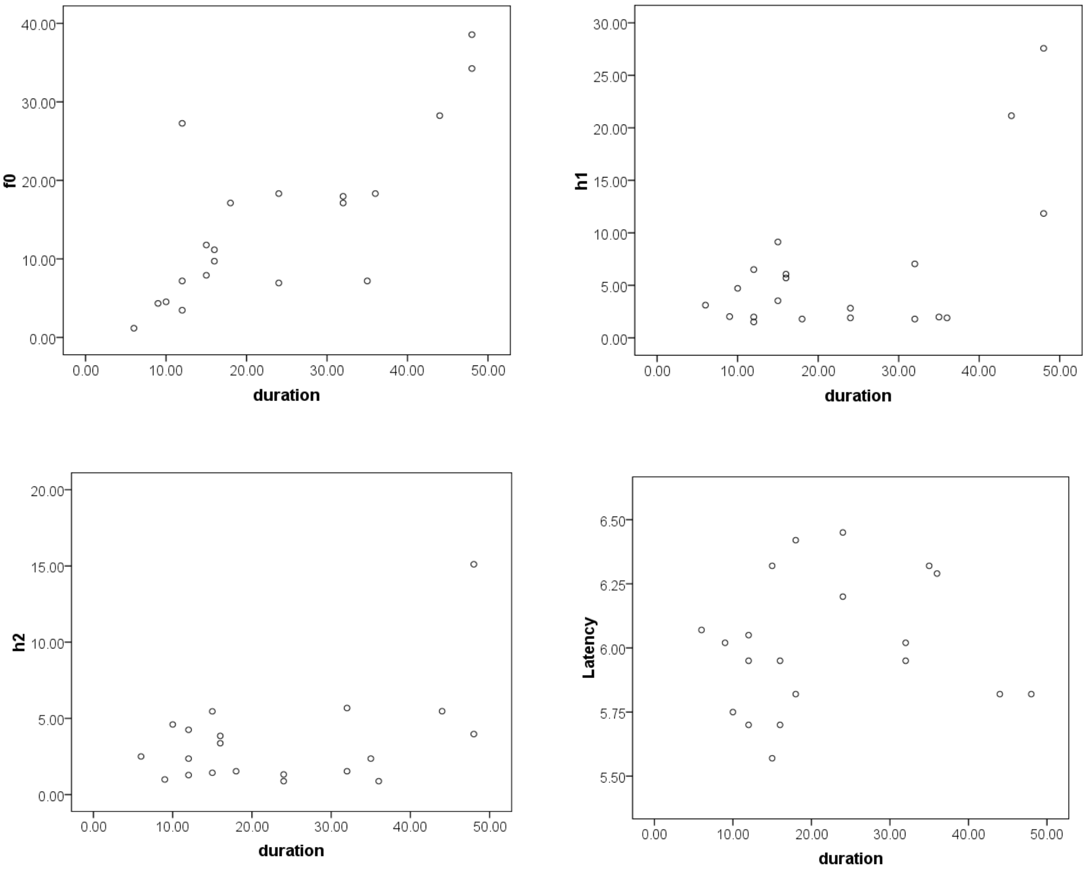

Figure 4.5 Scatter plots shows the relationship between amplitude of F0, H1, H2 and latency of peak V with duration of meditation in the 20 meditators.

It can be seen from the scatter plots that for fundamental frequency as the duration of meditation increases the amplitude of F0 also increases. Whereas, for other three scatter plots such relationship is not seen, that is with increase in duration of meditation there is not related increase in the values of H1, H2 and latency of wave V.

Then to study if this relationship has any significant correlation between the duration of meditation with amplitude of fundamental frequency, first harmonic, second harmonic and V peak latency of speech ABR responses in meditators, Non- parametric correlation tests were carried. Spearman's correlation coefficients was calculated to know the correlation between duration and other parameters of speech ABR response, which is tabulated in table 4.3.

Table 4.3

Correlation between F0, H1, H2 and peak V latency with duration of meditation in the meditation group.

Parameters	**Correlation Coefficient**	**Sig. (2-tailed)**
Amplitude of F0 (µV)	0.747	0.000*
Amplitude of H1 (µV)	0.248	0.298
Amplitude of H2 (µV)	0.189	0.425
Latency peak V (msec)	0.079	0.740

significant positive correlation

From Table 4.3 it can be observed that there is a significant positive correlation between amplitude of fundamental frequency (F0) of speech ABR with the duration of meditation in the individuals who practice meditation (p<0.01). This indicates that longer the duration of meditation practice better representation of fundamental frequency in the lower brainstem. However, no such correlation was seen for first two harmonics amplitude and latency of peak V with the duration of meditation.

Correlation between age of the participants who practice meditation and responses of speech evoked ABR (F0, H1, H2 and peak V latency).

A relationship was tried to establish between the chronological age of the participants in the meditation group with the speech evoked ABR. Before administrating the Spearman's correlation test to test the significance level of correlation, Scatter plots were made to understand the different data distribution between the age of the meditators and speech ABR parameters.

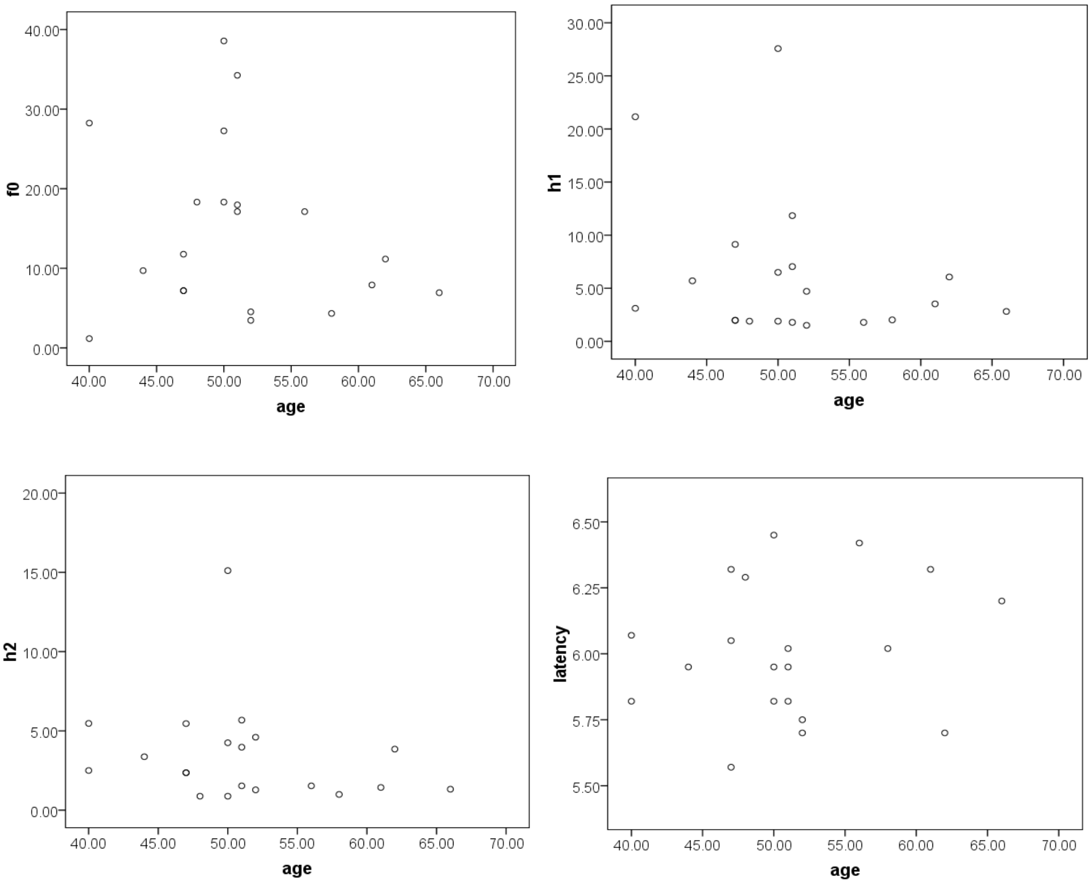

Figure 4.6 Scatter plots shows the relationship between amplitude of F0, H1, H2 and latency of peak V with age of the 20 meditators.

It can be seen from figure 4.6 that there is no definite trend for amplitude of F0, H1, H2 and wave V latency with increase in age.

To find out any correlation between chronological age of the meditators with amplitude of fundamental frequency, first harmonic, second harmonic and V peak latency of speech ABR responses in meditators, Non- parametric correlations were done. Spearman's correlation coefficients was calculated to know the correlation between chronological age and other parameters of speech ABR response, which is tabulated in table 4.4.

Table 4.4

Correlation between F0, H1, H2 and peak V latency with age of meditators in the meditation group.

Parameters	Correlation Coefficient	Sig. (2-tailed)
Amplitude of F0 (µV)	-0.19	.404
Amplitude of H1 (µV)	-0.21	0.373
Amplitude of H2 (µV)	-0.30	0.184
Latency peak V (msec)	0.016	0.946

From Table 4.4 it can be observed that there is a no correlation between amplitude of fundamental frequency (F0), first harmonic (H1), second harmonic (H2) and latency of peak V of speech ABR with the chronological age of the individuals who practice meditation ($p>0.01$). This can imply that encoding of speech in brainstem in meditators is independent, and is irrespective of age of the meditation practitioner.

Correlation between MAAS scores of the participants who practice meditation and responses of speech evoked ABR (F0, H1, H2 and peak V latency).

The relationship between speech evoked ABR and behaviorally obscured mindful attention awareness scale scores was also investigated using Spearman's correlation. Though Scatter plots were drawn before it and are graphically representing the relation between parameters of speech ABR and the mean MAAS scores.

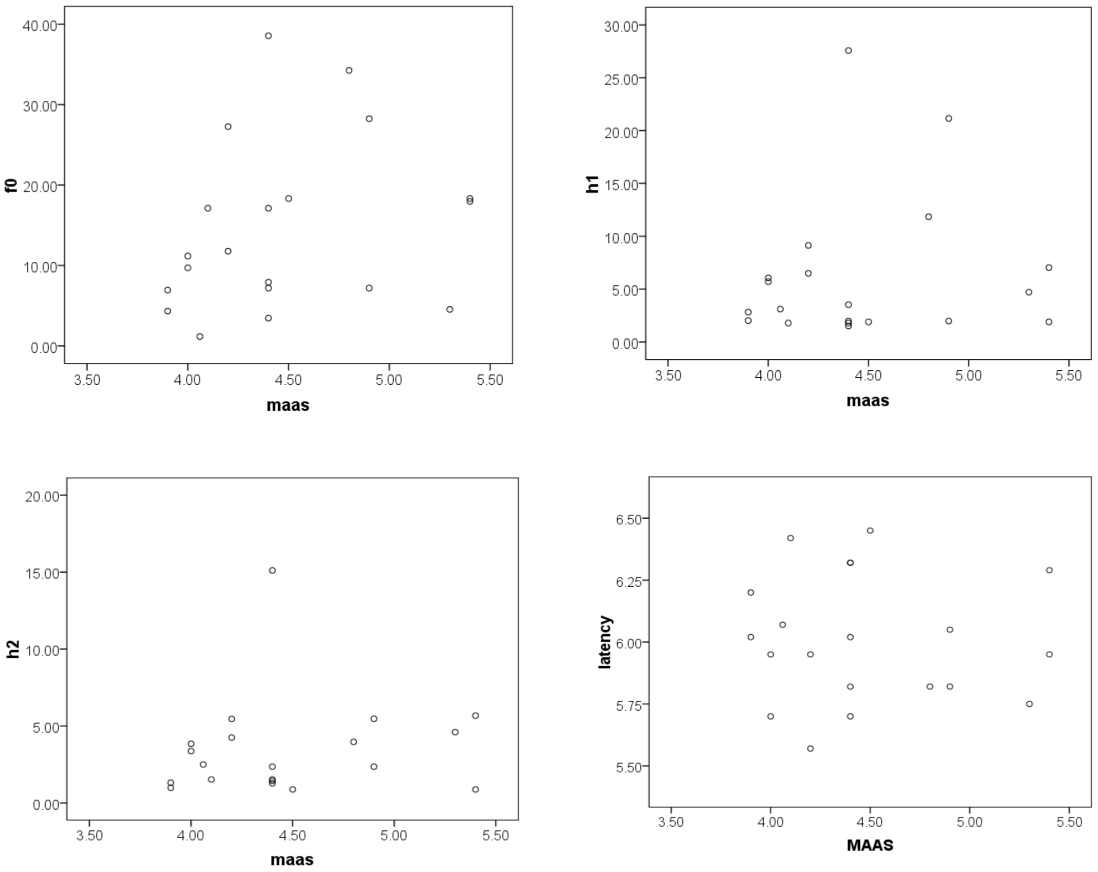

Figure 4.7 Scatter plots shows the relationship between amplitude of F0, H1, H2 and latency of peak V with mean MAAS scores of 20 meditators.

Scatter plots shows scattered distribution of the speech ABR parameters when correlated with the mean MAAS scores of the individuals who meditates. In the next step correlation was found out between mean MAAS scores of the meditators with amplitude of fundamental frequency, first harmonic, second harmonic and V peak latency of speech ABR responses in meditators, Non- parametric correlations were done. Spearman's correlation coefficients was calculated to know the correlation between chronological age and other parameters of speech ABR response, which is tabulated in table 4.5.

Table 4.5

Correlation between F0, H1, H2 and peak V latency with mean MAAS scores of meditators in the meditation group.

Parameters	**Correlation Coefficient**	**Sig. (2-tailed)**
Amplitude of F0 (µV)	0.38	0.090
Amplitude of H1 (µV)	0.06	0.797
Amplitude of H2 (µV)	0.18	0.426
Latency peak V (msec)	-0.02	0.909

From Table 4.5 it can be observed that there is a no correlation between amplitude of fundamental frequency (F0), first harmonic (H1), second harmonic (H2) and latency of peak V of speech ABR with the mean MAAS scores of the individuals who practice meditation ($p>0.01$). Hence, it shows that the scores of the MAAS questionnaire cannot predict the spectral coding of speech sounds in the brainstem.

It can be concluded from the above results that effect of meditation is seen only in encoding of fundamental frequency and not in other parameters of speech evoked auditory brainstem responses. Also, the amplitude of fundamental frequency is significantly positively correlated with the duration of practice of meditation that is longer the duration better is the encoding of F0 in the brainstem pathway. However, no such effect was seen for amplitude of first two harmonics and latency of peak V.

Chapter 5

Discussion

Present study aimed at studying the brainstem encoding of speech in individuals who practice meditation. The study also aimed at correlating the speech evoked ABR results in individuals who practice meditation with duration of meditation, age of the participants and MAAS scores. Results obtained in the study are discussed under following headings.

Speech evoked ABR parameters and meditation

Results revealed that encoding of fundamental frequency of the speech in the lower brainstem had significantly higher amplitude in the individuals who practice meditation when compared with non-meditators. It was also observed that amplitude of first harmonic and second harmonic and latency of wave V did not differ significantly in both the groups.

Both the groups of meditation and non-meditation had similar latencies of peak V that is non-meditators had mean latency as 6.03msec and meditation group had 6.00msec. Previous studies have also reported a latency between 6 to 7 msec for wave V of speech evoked ABR(Sinha & Basavaraj,2010; Neupane, Gururaj, Mehta & Sinha,2014).

Mean amplitude of fundamental frequency in non-meditation group was 6.99µv and in individuals who practiced meditation was 14.62µv, first harmonic is 3.02µv and 6.20µv and second harmonic amplitude is 2.11µv and 3.44 µv respectively. The overall values for Fo, H1 and H2 are almost similar to reported earlier in various studies (Anderson et al., 2012a; Neupane et al., 2014) in non-meditators group compared to the individuals who practiced meditation.

Wave V of speech evoked ABR is similar to the wave V of click evoked ABR. There are equivocal findings regarding the wave V latency for click stimulus in meditators. Deepeshwar & Telles, (2013) & McEvoy, Frumkin & Harkins(1980) a prolongation of latency of wave V in non-meditators group compared to meditators when assessed using clicks. The authors report that these meditators were doing meditation since long time and hence the latency may become better in individuals who are practicing meditation. However, there is also evidence for no significant differences in the peak V latency between meditators and non-meditators (Panjwani et al., 2000). Hence, there exists equivocal findings for peak V.

In the present study, a significant difference between the wave latency between the meditators and non-meditators was not observed. In the present study the participants were doing meditation from six months to 4 years. Earlier studies where the authors have reported the early latency of wave V (S Deepeshwar & Telles, 2013; McEvoy et al., 1980) in meditators who were practicing meditation since 6 to 9 years, It is possible that the early latency in wave V could be seen in meditators who are practicing meditation since long time. Panjwani et al.(2000) stated that effect of meditation is highly localised to cortical structures. There is no plasticity at the level of brainstem in mediators, and hence, no latency differences observed in both the groups. Meditation leads to improves information transmission in the areas concerned with complex processing of auditory stimuli (Telles et al., 2015). Hence, Enhanced amplitudes of fundamental frequency in our study are suggestive of better spectral representation of speech sounds in neural pathway in meditators than non-meditators. This is the first study which has reported the encoding of fundamental frequency in individuals who practice meditation.

Moreover, in another study, where click evoked ABR was recorded in individuals who practiced Qi Gong meditation, they found enhanced amplitudes for all the peaks. Such enhancement is not observed for all the peaks in our study as the stimulus used in both are different. That study also suggested that individuals who practice meditation have the capability of modulating the level of neural activity not only in the cortex but also at the level of brainstem (Liu et al., 1990). And since, it is already established that as an effect of meditation, persons who meditates have found to have increased cotico-thickness and increased grey matter (Kang et al., 2013). The increase in cortical thickness as a result of regular meditation practice hence, suggests the neural plasticity of the cortex (Lazar et al., 2005).

One of the mechanisms for brainstem plasticity has top–down influences, which is originating from complex, multisensory training, and guiding the plasticity in peripheral areas (Musacchia et al., 2007). This theory however, is derived from the reverse hierarchy theory, which states that learning modifies the neural circuitry that governs performance, beginning with the highest level and gradually refining lower sensory areas (Ahissar & Hochstein, 2004). And as it has been reported that the cortical system can modulate the activity of the brainstem (Parbery-Clark et al., 2012**.** Furthermore, it is already established that representation of speech sounds in brainstem are plastic (Kraus & Nicol, 2003). It is suggestive of some anatomical changes, taking place in the brainstem too, as an effect of meditation, which has been reflected in our study as increment in amplitude of fundamental frequency.

It has been suggested that the transient response and frequency following responses elicited by speech stimuli reflect two different neural mechanisms within the brainstem (Akhoun et al., 2008). There was a difference between encoding of transient and the sustained responses among the meditators. Probable neural mechanism which is responsible for generations of sustained response are more plastic compared to the mechanism responsible for generation of transient responses. This might have resulted in differential effect on both the transient and sustained response.

The evidence for a different site of generation of the transient versus sustained responses also comes from the effect of noise or higher repetition rate on speech evoked ABR. Nicole Russo, Nicol, Musacchia, and Kraus (2004) and Cunningham et al. (2001)in their studies have reported that the background noise affects the latency of the onset responses more than the latency of the frequency following responses. Furthermore, increasing the repetition rate of the stimuli selectively affects the latency of the onset responses and does not affect the latency of the sustained responses (Krizman, Skoe, & Kraus, 2012). The latency of peaks provides an insight to neural firing synchrony and accuracy of brainstem to mimic the stimulus. Whereas, the magnitude of the amplitude suggests robustness of brainstem to speech stimulation and size of the spectral components (Johnson, Nicol, & Kraus, 2005).

Correlation between Speech evoked parameters and duration of meditation, age of meditators and MAAS scores

A positive correlation was seen in duration of practice of meditation to amplitude of F0. However, no such correlation was seen for H1, H2 and wave V latency with duration of meditation practice. No correlation of all the speech parameters with age of the meditators and mean MAAS scores was revealed.

Even though F0 in the actual speech signal has less energy, F0 gets coded in the neural system. In our study however, it was noted that this encoding of F0 was rather coded with higher amplitude in the individuals who practiced meditation. Hence, representing the higher strength of pitch encoding (Moore, 2003). Because correlation was seen between the F0 amplitude and duration of the meditation practice, it may be that encoding enhancement depends on how well and consistent the practice was. Increase in amplitude of F0 was significantly positively correlated with the increase in the duration of meditation. Similar findings were seen in a study where an overall increase in amplitude in all five peaks of click-ABR in meditators was observed(Liu et al., 1990). This relationship with duration of meditation and neural encoding of speech was seen in our study with the amplitude of fundamental frequency. However, this correlation was not observed with latency of peak V. This can be reasoned that as the latency of peak V depends on the intensity of the stimulus (T. W. Picton, Woods, Baribeau-Braun, & Healey, 1977). Hence, it cannot be considered as a parameter to study the effect of meditation.

The difference in our results when compared to other studies can also be accounted to the fact of quantifying the efficacy of meditation. One of the limitations of previous studies was not to report whether they took effective meditators in the study or not (Delgado-Pastor, Perakakis, Subramanya, Telles, & Vila, 2013; McEvoy et al., 1980; Panjwani et al., 2000; Singh & Telles, 2015; Telles et al., 2015). However in our study we conducted a questionnaire of mindful attention awareness scale (MAAS) (K. Brown, 2016). This questionnaire correlates with the mindfulness dimension of the meditation (Reavley & Pallant, 2009) and hence, accordingly assuring participants meditation efficacy. However, no correlation of MAAS scores and speech ABR parameters was seen. It can be because of the fact like both assess different mechanism, one cognitive and other neural functioning, respectively.

Summary and conclusion

Meditation is a compound mental tasks. It’s a practice which leads to various changes related to anatomy and physiology of the practioner. Along with cognitive changes, electrophysiological changes have also been observed in the individuals who practice meditation.

Present study was conducted with the objective of finding out the difference in speech encoding among individuals who meditate than to those who do not practice meditation. And to find out if there is any correlation between the duration of meditation, chronological age of meditators and mean Mindfull Attention Awareness Scales scores and the brainstem encoding of speech sounds.

20 Individuals who practice meditation with a minimum period of 6 months, and have adequate scoring in MAAS were taken in the meditation group. And non-meditation group had 20 age matched participants with no experience of meditation. Both groups had age range of 40-70 years of age. Speech evoked ABR was recorded in all the participants.

Speech evoked ABR was recorded by using a 40 msec. BioMark /da/ for all 40 right ears. Repitition rate was kept 10.9/sec at an intensity of 80dBnHL for 1500 sweeps. Recorded responses were filtered between 100 to 3000 Hz and within a time window of 74 msec (10msec as pre-stimulus timing).

Statistical analysis was done on the obtained data using descriptive statistics, Mann Whitney U, and Spearman’s correlation through SPSS software (version 17.0). The following results were obtained in the present study:

1. Significantly higher amplitude of fundamental frequency in the meditation group as compared to non-meditation group.

2. No significant difference seen in meditation and non-meditation group in terms of harmonic amplitude and wave V latency.

3. No correlation of harmonics and wave V latency was seen with duration of meditation practice, age of the participants in meditation group and mean MAAS scores.

4. There was a significant positive correlation between duration of the meditation and the amplitude of fundamental frequency.

To conclude, the representation of robust feature of the speech signal at the brainstem was better in meditators compared to that of non-meditators. This implies that the meditation leads to alter the functioning of encoding of speech sounds in individuals who practice it on a regular basis. Longer the duration, better is the encoding in neural pathways, hence more plasticity. Since, these effects are slowly emerging; we can recommend the practice of meditation to the older adults to restrict the detrition of speech perception associated to aging.

Implications of the study

- The study helped us to understand the mechanism of speech encoding (F0, H1 and H2) at the brainstem level in individuals who practice meditation as compared to those who don’t.

- The study was helpful in understanding the effect of meditation on brainstem neural plasticity in meditators.

- Like music training, meditation practice can lead to offset of age related deterioration.

- It adds on to the literature.

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