EFFECT OF DIFFERENT SPEECH STIMULI ON ACOUSTIC CHANGE COMPLEX IN MUSICIANS

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Registeration No. 13AUD030

This Dissertation is submitted as partfullfillment for the Degree of Master of Science in Audiology University of Mysore, Mysore

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May, 2015

CERTIFICATE

This is to certify that this dissertation entitled **"Effect of different speech stimuli on Acoustic Change Complex in musicians"** is a bonafide work in part fulfillment for the degree of Master of Sciences (Audiology) of the student (Registration No. 13AUD030). This has been carried out under the guidance of a faculty of this institute and has not been submitted earlier to any other University for the award of any other Diploma or Degree.

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DECLARATION

This is to certify that this dissertation entitled **"Effect of different speech stimuli on Acoustic Change Complex in musicians"** is the result of my own study under the guidance of Dr. Prawin Kumar, Lecturer 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.

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Dedication

Dedicated to my Mummy, Papa, Anurag and Vishal

ACKNOWLEDGMENTS

- *My sincere thank to **God** almighty for giving me courage and determination for completing this dissertation.*
- *I would like to thank **Dr. S. R. Savithri, Director** , ALL INDIA INSTITUTE OF SPEECH AND HEARIN MYSORE, for permitting me to carry out this study.*
- *I would like to thank the **Dr Ajith Kumar**, **HOD, Department of Audilology**, for allowing me to use the department for carrying out the study.*
- *Words are inadequate to express my deep sense of gratitude to my guide **Dr. Prawin Kumar** for his invaluable guidance. I cannot dream about this dissertation without his strong support, guidance and co-operation. Thank you sir for guiding me.*
- *Nonetheless, I would also like to extend my sincere thanks to **Ganapathy sir, Sriraj sir, Vikas sir, Kishore sir, Jithin sir, Spoorthi ma'am and Dipashree ma'am** for their timely support and help.*
- *I express my heartfelt thank to all the **faculty of AIISH.***
- *THANK YOU **Mom and Dad** for their unconditioned love and extreme support. For supporting me in all my decisions specially the one of studying in AIISH for 6 years.*
- *Special thanks to a special person **Anurag** for being my mentor, my guide, my friend and for all his effort and support in helping me during this Dissertation. Thanx for everything you have done for me.*
- *Thanx to my lovely bro **Vishal**, for being my strength throughout this journey.*
- *Thanx to the '**Tripty Gang''** Mukesh bhaiya, Medha di, Anjana di, Suchi di for making this journey of AIISH full of fun and laughter.*

- *Thank you to my best pals* ***Tithi and Tanvi (T^2)*** *for always being there with me in this roaler coaster ride. Love u guys and will miss u a lot guys. Thank you* ***Himanshu(ji)*** *for always encouraging me in studies like my brother.*

- *Thanx to the* ***"New Block Jawans" Aisha, Swati and Rohan (chucha)*** *for making this data collection get over in a smoothy and exiting way. U guyz rock.*

- *Thanx to my* ***'Raipur friends' Tulsi and Neelesh****. U guyz are awesome and I had a nice time with you.*

- *Thank you to my adorable juniors* ***Shalini, Preeti, Rashika, Shruti Sahani, Keshav, Appas, Biswajit and Neha(I B.Sc).***

- *I am heartily thank ful to all my* ***subjects*** *for giving their precious time for this dissertation.*

- *Thanx to my* ***school friends*** *and my dear batchmates of B.Sc and M.Sc* ***(Standard Deviators & Master's stay connected).***

- *Thank you to* ***everyone*** *who had helped me in completing this dissertation.*

I WOULD LIKE TO END THIS WITH A SAYING

"ARISE, AWAKE AND STOP NOT UNTIL THE GOAL IS ACHIEVED"

Abstract

Studies done on neurosciences reveal that intensive learning experiences such as musical training involve changes in brain functions. Practicing music over a period of time optimizes neuronal circuits and also strengthens the synaptic connections. These changes can be assessed using a higher cortical potential such as Acoustic Change Complex (ACC) which is a potential tool in accessing the speech perception ability. The present study aims at finding the effect of different speech stimuli on acoustic change complex in trained musicians and compared with non-musicians. There were 34 individuals comprises of 17 musicians and 17 non-musicians, participated in the study. ACC was recorded using three speech stimuli (/sa/, /si/ & /su/) for both the groups. Overall, results of the study reveals that musicians have earlier (better) latencies and larger peak-to-peak amplitude as compared to non-musicians. One way repeated measure ANOVA showed significant difference in latency of P1 and P2 across three speech stimuli and latency of 2N1 and 2P2 between musicians and non-musicians. Further, Peak-to-peak amplitude of N1-P2, P2-2N1, and 2N1-2P2 were significantly different across three speech stimuli and peak-to-peak amplitude of N1-P2 between musicians and non-musicians. The above finding seen in musicians could be due to improvement seen in auditory memory which shapes composite (P1–N1) measures or pitch-specific encoding (F0) in a co-coordinated manner which leads to superior discrimination of syllables that required resolution of temporal cues. Thus, the present study can be applied on the population with neurological deficit for monitoring the cognitive improvement which can be seen due to musical training.

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Chapter 1

Introduction

Auditory evoked potentials (AEPs) are defined as small changing voltages which are elicited using auditory stimuli. These potentials are divided into various categories based on the latency, amplitude and the origin of the potentials. The cortical event related potentials (ERPs) are “slow” and “late” potentials that occurs at least 50 ms following stimulus onset, recorded in response to the auditory stimuli (Katz, 2009). These responses are mainly used for studying maturation (Martin, Shafer, Morr, Kreuzer, & Kurtzberg., 2003; Wunderlich, Cone, & Shepherd; 2006), and aging process (Cooper, Todd, McGill, & Michie., 2006; Martin & Jerger, 2005). CAEP’s are also used to assess auditory system in clinical population such as in sensory neural hearing loss (Korczak, Kurtzberg & Stapells., 2005; Oates, Kurtzberg & Stapells., 2002), and cochlear implants (Sharma, Dorman, & Spahr., 2002; Gordon, Tanaka, & Papsin., 2005). Acoustic Change Complex (ACC) is a type of ERPs recorded in response to the change(s) in the ongoing stimuli in terms of frequency, intensity and duration. As waveform reflects the acoustic change contained in the stimuli it was termed as ACC by Martin and Boothroyd (1999). This complex is basically a response to transition from fricative to vowel (Ostroff, Martin & Boothroyd.,1998), intensity, frequency, and phase modulations in sustained tones (Jerger & Jerger., 1970; Näätänen & Picton., 1987; Dimitrijevic, John, Vanronn & Picton., 2001), periodicity (Martin & Boothroyd, 1999). ACC can also be recorded in two consonant-vowel syllables (CVCV) combination such as /daDa/ which is different from the typical CV (e.g. /da/) or VV (e.g. /ui/) combination as studied by Small and Werker (2012). ACC causes discrimination at the level of the auditory cortex and provides insight into the brain's capacity to process the acoustic features of speech (Ostroff et al., 1998). As seen in ACC, sensory encoding of the auditory stimulus is primarily reflected by P1 and N1 latency whereas N2 and 2P1 are endogenous in nature i.e. they are affected more by attention and cognition (Sharma, Dorman & Kral., 2005). In children P1 peak is more robust (Kushnerenko et al., 2002) whereas in adult N1 is more robust. As reported by various studies, ACC is used in various populations such as in children (Juneja & Devi., 2011; Spoorthy & Devi., 2012), adults (Ganapathy, Narne, Kalaiah, & Manjula., 2013; Shetty & Manjula., 2012), individuals with auditory neural spectrum disorder (Srikar & Narne., 2011), Hearing aid users (Jobish & Sriraj., 2012), cochlear implant users (Brown, Etler, He, O'Brien, Erenberg, Kim, & Abbas., 2008). As compared to other potentials it elicits responses with larger amplitudes and better signal-to-noise ratios, thus requiring less time and fewer stimulus presentations for recording (Martin & Boothroyd, 1999). Based on the finding CAEPs recorded in the musicians showed earlier peaks, better F0 discrimination and enhanced amplitude (Musacchia, Strait, & Kraus, 2008; Musacchia, Sams, Skoe, & Kraus, 2007). As suggested by the investigators, ACC may be an useful tool in the assessment of auditory perception capacity (Kaukoranta, Hari, & Lounasmaa, 1987; Ostroff., 1999). Thus, ACC can be helpful potential in tapping the placticity of brain in trained musicians.

Music is an important part of human culture. It mainly involves sensorimotor functions for processing and production of music. Primary and secondary sensory areas are involved in music as they provide necessary tactile and kinesthetic feedback during production of music in terms of singing or playing an instrument. Neuroscience study done by Fujioka, Ross, Kakigi, Pantev and Trainor (2006) reveals that musical training causes visible changes in the structure and functioning of brain especially, in frontal lobe as confirmed non-invasively by electroencephalogram (EEG) or the magnetoencephalogram (MEG) extra-cranially. Practicing music maily leads to optimization of neuronal circuits by changing the number of neurons involved and the timing of synchronization and the number and strength of excitatory and inhibitory synaptic connections.

1.1 Need for the study

Literatures suggested that acoustic change complex may be a potentially useful tool in the assessment of auditory perception capacity. This assumption has been based on the uses of ACC in different group of populations (Ganapathy, Narnae, Kalaiah, & Manjula., 2013; Juneja & Devi., 2011, Shetty & Manjula., 2012). As mentioned in the above studies speech stimuli could give more information regarding encoding of stimulus when used in CV combination which has properties of spectral change, amplitude change and change in periodicity. It also noticed to be having good test-retest reliability in adults (Tremblay, Friesen, Martin & Wright., 2003). Therefore, there is a need to determine whether a significant difference exists between formally trained musicians and non-musicians for event related potential such as Acoustic Change Complex (ACC). Further, present study also tried to explore the changes due to presentation of different speech stimuli in musicians if any. There is a dearth of literature to explore the utility of different speech stimuli in musicians using acoustic change complex. Hence, present study is taken up to find the changes if any occur due to different speech stimuli in acoustic change complex potential.

1.2 Aim of the study

To find out the effect of different speech stimuli on acoustic change complex in trained musicians.

1.3 Objective of the study

- To determine the changes due to different speech stimuli on latency and amplitude of acoustic change complex in musicians.
- To determine the changes due to different speech stimuli on latency and amplitude of acoustic change complex in non-musicians.
- Comparison between musicians and age matched non-musicians on acoustic change complex for different speech stimuli.

Chapter 2

Literature Review

2.1 Auditory evoked potentials

The auditory evoked potentials (AEPs) are electrical responses of the auditory nervous system elicited by auditory stimuli (Stapells, Picton, Abalo, Read, & Smith, 1985; Gelfand, 2007). AEPs are classified based on various dimensions such as time of occurrence (early, middle and late responses), anatomy (electrocochleography and auditory brainstem responses), based on response generation (exogenous and endogenous); or specific generator properties (stimulus and event related) as described by Goldstien and Frye-osier (1984). Cortical Auditory Evoked Potentials (CAEPs) is used to monitor the functioning of central auditory pathways and also to monitor the development of auditory cortex. CAEPs are believed to reflect the activities of excitatory post-synaptic potentials at the level of thalamus and higher auditory cortex (Wunderlic et al., 2006). Cortical auditory evoked potentials (P1-N1-P2 complex) have been extensively used to understand sound processing in the human auditory system. These CAEPs electrical potential recorded from the auditory area of the cortex following presentation of acoustic stimulus) are believed to reflect the neural encoding of sound signal (Hillyard, Picton & Regan., 1978), but they do not provide any viable information regarding discrimination of sounds. The CAEPs do not index behavioural discrimination (Martin & Boothroyd, 1999), rather they provide an index for encoding of acoustic event by the cortical neurons (Hillyard, Picton & Regan., 1978; Picton et al, 2000). CAEPs have been recorded using various stimuli, such as tone bursts, clicks (Eggermont, Ponton, Don, Waring & Kwong., 1997), synthetic speech stimuli (Sharma et al., 2002), musical notes (Jones, Longe & Pato., 1998) and natural speech stimuli (Tremblay et al, 2003; Kaukoranta et al.,1987). The N1-P2 complex is seen in the average of waveforms recorded for simple sound stimuli, such as tone bursts and clicks.

2.2 Acoustic Change Complex

It has been noticed that for a complex stimulus with acoustic changes within the ongoing sound stimulus, multiple overlapping N1-P2 complexes were recorded (Naatanen & Picton, 1987; Kaukoranta et al., 1987; Martin & Boothroyd, 1999). Research findings suggest that the ACC indicates discrimination at the level of the auditory cortex and provides insight into the brain’s capacity to process the acoustic features of speech (Kaukoranta et al., 1987; Ostroff, Martin & Boothroyd., 1998). The ACC has been recorded in response to intensity, frequency, and phase modulations in sustained tones (Jerger & Jerger, 1970; Näätänen & Picton, 1987; Yingling & Nethercut, 1983; Dimitrijevic et al., 2008). The ACC has also been recorded in response to changes of periodicity (Martin & Boothroyd, 1999), amplitude and spectrum (Martin & Boothroyd, 2000). In respose to change in the amplitude using /uu/ and /ui/ as the stimuli there was no significant change found in acoustic change complex as studied by Martin and Boothroyd (1999). Ostroff (1999) has demonstrated that the ACC shows good agreement with behavioural tests of frequency discrimination as small as 38 Hz in the second formant of synthetic, three- formant vowels, which are considered a threshold for defining vowel contrast. Tremblay et al (2003) used speech syllables such as /bi/, /pi/, /si/, and /ò i/ for recording CAEP and found that the syllables /bi/ (duration of /b/ was 5.1

ms from voice onset time, and that for /i/ was 478.9 ms) and /pi/ (duration of /p/ was 65.4 ms, and for /i/ was 457.8 ms) evoked single N 1-P 2 complex, but the syllables /si/ (duration of /s/ was 250 ms and for /i/ was 506 ms) and / ò i/ (duration of / ò / was 220 ms and for /i/ was 434 ms) elicited multiple overlapping N1-P2 complex which suggests that ACC is not always recorded because of overlapping components. The overlapping responses are elicited due to short pre-transition duration which can be separated and studied by using subtraction method (Ostroff et al., 1998). The ACC has also been elicited to simple syllables at the transition from consonantal segment to vocalic segment (Hari., 1991; Kaukoranta et al., 1987; Ostroff et al., 1998). The Acoustic Change Complex reflects features of the underlying acoustic patterns. Such potentials may have value in the evaluation of speech perception capacity in hearing impaired children (Ostroff et al., 1998). Shetty and Manjula (2012) studied the gender and trasducer effect in the Acoustic Change Complex using /sa/ and /si/ stimuli and found there was no significant difference among two transducers (headphones and loudspeakers) for both the stimuli. The study further revealed that the latency of 2N1 was earlier and the amplitude of N1 and P2 was more for female participant as compared to male.

Furthermore, when compared to other ERPs, such as MMN, the ACC elicits responses with larger amplitudes and better signal-to-noise ratios, thus requires less time and fewer stimulus presentations for recording (Martin & Boothroyd, 1999). These advantages can be very important for testing infants and other populations that are difficult to test. As a result, the ACC has the potential to be a viable tool for determining neural encoding abilities.

2.3 Stimuli and transition duration

ACC has been recorded using speech and non-speech stimuli such as consonant-vowel transition (Kaukoranta et al, 1987; Ostroff et al., 1998; Tremblay, Billings, Friesen & Souza., 2006), periodicity changes (Martin & Boothroyd., 1999), amplitude and spectral variations (Martin & Boothroyd., 2000) in which the duration of pretransition stimulus ranged from ~ 100 ms to ~ 400 ms (Kaukoranta et al, 1987; Ostroff Martin & Boothroyd., 1998; Martin & Boothroyd., 1999, 2000; Tremblay et al, 2003, 2006). A comparison of ACC elicited by stimulus like: click, tone and speech stimulus reveals a significant difference in the morphology obtained. Response is comparatively better with speech stimuli than when compared to tone and click stimulus. Ostroff (1999) has investigated cortical potentials in response to naturally produced speech syllable /sei/ and a typical N1-P2 complex has been recorded to the acoustic change from /s/ to /ei/. The finding suggested that the ACC reflects changes of cortical activation caused by amplitude or spectral change at the transition from consonant to vowel and it may have the potential todemonstrate discrimination capacity. Test retest study done on Acoustic Change Complex using click, tone and different CV combination of both plosive vowel /pi/ and /bi/and fricative vowel such as /si/ and /ʃi/ reveals a significant difference in the morphology obtained and the response is comparatively better with speech stimuli than when compared to tone and click stimulus (Trambley et al., 2003). The Acoustic Change Complex was recorded varying the duration of pre transition stimulus from ~ 100 ms to ~ 400 ms (Kaukoranta et al, 1987; Ostroff et al, 1998; Martin & Boothroyd, 1999, 2000; Tremblay et al, 2003, 2006). The minimum pre- transition duration required for eliciting

ACC was 80 ms for speech stimuli and 100 msec for non- speech stimuli (like pure tone) (Ganapathy et al., 2013). Infant perception was also accessed by using ACC in a study done by Small and Werker (2012). Participants were 25 infants (4 month of age) and 6 adults. ACC was recorded using CVCV combination . The authors concluded that ACC was not being elicited as the stimulus. Investigators reveal that P1-N1-P2 complex shows there are significant changes in the morphology with maturation (Ponton, Eggermont, Khosla, Don & Kwong, 2002).

2.4 Application of ACC

Acoustic change complex has a great application in evaluating the subjects with auditory neuropathy spectrum disorder as studied by Srikar and Narne (2011) in which they observed that individuals who demonstrated the presence of ACC had good speech recognition abilities compared to individuals with absence of ACC. Spoorthy and Devi (2012) obtained the correlation between behavioral measure and Acoustic Change Complex and the results showed a positive correlation between amplitude measures and speech in noise scores. Based on the neuronal maturation, Juneja and Devi (2011) investigated ACC in children of three different age groups and found that younger subjects had longer latency and lesser amplitude than older subjects. Systematic changes were observed in N1-P2 and N2-P3 complexes. Significant age effect was seen across N2-P3complex. To evaluate the usefulness of hearing aid across degree of hearing loss, Jobish and Sreeraj (2012) compared ACC in aided and unaided condition and found that ACC was present in aided conditions. Shetty in 2014, found significant difference at the level of transition for subjects with poor performance with hearing aid in comparison to individual with good performance in hearing aid in ACC, mainly in 2N1 peak. Usefulness of cochlear implant was also evaluated by Brown et al., 2008, found the feasibility of recording the electrical acoustic change complex in response to changes in stimulating electrode position from individual cochlear implant users. Juneja, Rana, Kumar and Santosh in 2011 studied acoustic change complex in subjects with and without stuttering and results revealed that there was no significant difference in both latency and amplitude measures of acoustic change complex suggested that the auditory cortical processing for speech stimuli in persons who stutter was similar to persons who don’t stutterer.

2.5 Neuroplasticity in Musicians

Playing a musical instrument is an intense, multisensory, and motor experience that usually commences at an early age and requires the acquisition and maintenance of a range of skills over the course of a musician's lifetime. Thus, musicians offer an excellent human model for studying the brain effects of acquiring specialized sensorimotor skills. Music making places unique demands on the nervous system and leads to a strong coupling of perception and action mediated by sensory, motor, and multimodal integrative regions distributed throughout the brain (Schlaug, Altenmüller, & Thaut., 2010). Indeed, researches have demonstrated that intense musical training can result in plastic changes in the developing brain as well as the adult brain (Gaser & Schlaug 2003; Hyde et al.,2009).Neuroanatomical studies reveals that music processing occurs bilaterally in the brain, a degree of hemispheric specialization has been demonstrated, with the right auditory cortex particularly involved in spectral processing for timbre and fine-grained pitch discrimination, as well as the perception of melodic contour (Stewart, Von-Kriegstein, Warren, & Griffiths, 2006; Hyde, Peretz, & Zatorre, 2008).

The extent to which early training influences plasticity in other brain regions is uncertain. Studies of the pre-central sulcus, central sulcus, and corticospinal tract have found negative correlations between the degree of structural change and age at commencement of training (Amunts, Istomin, Schleicher & Zilles., 1995; Imfeld, Oechslin, Meyer, Loenneker & Jancke., 2009; Li, et al., 2010), but studies of the cerebellum and planumtemporale have not shown a significant correlation (Hutchinson, Lee, Gaab & Schlaug., 2003; Keenan, Thangaraj, Halpern, & Schlaug, 2001). A significant correlation between the age of onset of musical training and the size of N1b responses in musicians, with those starting lessons after age of 10 was not showing effect was seen by Pantev et al. (1998). Similar findings were seen in size of later component P3 by Trainor, Desjardins, & Rockel (1999). In 1995 study of the corpus callosum, Schlaug and colleagues found that their results only held for the group of musicians who began their music training prior to age seven, while those who began their training after age seven did not have a significantly larger corpus callosum than non-musicians. Thus, experiences that occur during early, sensitive periods of development are expected to have a greater impact on brain structureand function which leads to larger changes in the auditory cortex. The musical instrument of training may also play a large role in the type and location of neuroplastic changes. Specialization may lead to instrument-specific modification since motor and sensory demands vary between instruments. In a study elegant in its simplicity, Bangert and Schlaug (2006) showed that the shape of the central sulcus could differentiate not only musicians and non-musicians, but it could also differentiate between keyboard and string players within the musician group.

2.6Auditory evoked potentials in Musicians

Musicians demonstrate psychoacoustic and physiological enhancements at the early stages of auditory processing in the brainstem and the cochlear efferent pathway. Musicians show reduced transiently evoked otoacoustic emissions to clicks with contralateral auditory stimulation, which suggests stronger feedback to the cochlea from the brainstem, as well as reduced loudness adaptation to continuous tones (Micheyl, Carbonnel, & Collet, 1995; Micheyl, Khalfa, Perrot, & Collet, 1997). Musicians also show shorter latency in brainstem responses to auditory and audio-visual speech stimuli (Musacchia et al., 2007). Additional, the fundamental frequency (F0) of speech sounds from both tonal and non-tonal languages is better represented by musicians in the 'frequency following response'. This forms part of the auditory brainstem response, and includes stronger F0 response amplitude and better phase locking (Musacchia, et al., 2007; Musacchia et al., 2008; Wong, Skoe, Russo, Dees, & Kraus, 2007). Evidences support that the brains of musicians and non-musicians respond differently to auditory and tactile stimuli as associated with musical task as musical skill is also associated with increased sensitivity of the P300 event related potential to disparities in melodic contour and pitch interval (Trainor et al., 1999), it enhanced neuromagnetic responses evoked by tactile stimulation of the fingering digits of violinists and structural enlargement of the anterior corpus callosum (Schlaug et al., 1995), and anterio medial region of Heschel's gyrus (Schneider et al., 2002) is also seen in musician as compared to non-musicians.

Further, musical training leads to anatomical, functional and event related specialization, as they have more neuronal cell bodies (gray matter volume) in areas of brain such as auditory, motor and visual areas (Gaser & Schlaug, 2003) and also have more axonal projections connecting the right and the left Hemisphere (Schlaugh et al., 1995). Therefore, an enhancement of cortical potentials is seen in musicians as compared to non-musicians. Auditory training leads to enhancement of P2 auditory evoked potentials in adults and children as young as 4 years as compared to the non-musician adult and children (Trainor, Shahin & Roberts, 2003). Vuust, Brattico, Seppänen, Näätänen, Tervaniemi (2012) studied MMN on musicians using a novel, fast and musical sounding multi-feature paradigm, to six types of musical feature change in musicians playing three distinct styles of music (classical, jazz, rock/pop) and in non-musicians and reported that that the characteristics of the style/genre of music played by musicians influence their perceptual skills and the brain processing of sound features embedded in a musical context. Musicians' brain is hence shaped by the type of training, musical style/genre, and listening experiences.

A study done by Fujioka et al. (2006) using Magneto-encephalography on 4 to 6 years old children showed a clear musical effect as larger and earlier N250 m peak in the left hemisphere in trained children as compared to untrained children. Thus, the study suggests that difference is present in the cortical potentials among musicians in comparison to non-musicians. Similarly, Akin and Belgin (2009) administered Differential Limen of frequency and pure tones on 32 individuals aged between 19 and 28 years to find the difference between musician and non-musicians group. The results revealed that musically trained participants had performed better than untrained participants in frequency discrimination tasks. The study concludes that musical training increases the spontaneous attention to the sound heard and the ability to discriminate.

Chapter 3

Method

3.1 Participants

Two groups of subject participated in the study i.e. Experimental and control group. Experimental group consisted of 17 adult musicians with experience of minimum 5 years training in Indian classical music in the age range of 18 to 30 years (mean age of 20.23 years). Control group consisted of 17 age-matched adult non-musicians who did not attended any formal training in music in the age range of 18 to 30 years (mean age of 19.82 years).

3.2 Subject Selection Criteria

All the participants had hearing thresholds within normal limits as defined by pure tone thresholds (<15dB HL) for 250 Hz, 500 Hz, 1000 Hz, 2000 Hz, 4000 Hz and 8000 Hz pure tones. They had normal middle ear functions as revealed by 'A' type of tympanogram and presence of acoustic reflexes at 500 Hz, 1000 Hz, 2000 Hz & 4000 Hz for both ipsilateral and contralateral stimulation. In addition, participants also had presence of transient evoked otoacoustic emission which indicates normal outer hair cell functioning. Further, participants involved in experimental group had minimum of 5 years of musical training in Indian classical music, whereas, participants involved in the control group, had not undergone any formal musical training. Those participant who had any conductive pathology or cochlear pathology, as well as any neuromuscular or, neurological deficit were excluded from the present study.

3.3 Testing environment

All the behavioural as well as electrophysiological tests were being carried out in a electrically shielded sound treated room. The noise levels were kept as per the guidelines in ANSI S3.1 (1991).

3.3 Instrumentation

Calibrated double channel clinical audiometer (Inventis Piano) was used for pure tone audiometry. For immittance evaluation, calibrated GSI-Tympstar middle ear analyzer was used. For recording of transient evoked otoacoustic emission, ILO (Version 6) was used. Biologic Navigator Pro (Version7) was used to record click evoked auditory brainstem response (ABR) and Acoustic Change Complex (ACC).

3.5 Procedure

3.5.1 Puretone audiometry and Immittance evaluations. Pure tone thresholds were obtained using modified version of Hughson and Westlake procedure (Carhart & Jerger, 1959) across octave frequencies from 500 Hz, 1000 Hz, 2000 Hz, 4000 Hz and 8000 Hz for air conduction and frequencies from 500 Hz, 1000 Hz, 2000 Hz and 4000 Hz for bone conduction. Immittance evaluation was carried out with a probe tone frequency of 226 Hz for tympanometry and ipsilateral and contralateral reflexes. Acoustic reflexes thresholds were measured at 500 Hz, 1000 Hz, 2000 Hz, and 4000 Hz. Transient evoked otoacoustic emissions were recorded and considered as responses only when signal to noise ratio (SNR) was greater than 6 dB at three consecutive frequencies as given by Harison and Norton (1999).

3.5.2 Electrophysiological Testing

Auditory Brainstem Response was being carried out to rule out the presence of retro-cochlear pathology in both the groups. Biologic Pro Navigator was used to carry out the recording in 2 channelsetting using click stimuli with the time window kept till 12msec. The skin surfaces were cleaned at the Cz and both the mastoid (M1 and M2) with skin abrasive, to obtain skin impedance of less than 5 kΩ for all electrodes. AgCl electrodes were used for recording of ABR. The electrodes were placed with the help of skin conduction paste and surgical plaster to secure them tightly in the respective places. Participants were made to sit on reclining chair and were instructed to relax and refrain from extraneous body movements to minimize artifacts. The details about the protocol used for recording is mentioned in table 3.1.

AcousticChange Complex (ACC) was being carried out for all the subjects participated in the study with analysis time of900ms and filter setting of 1 to 30Hz. The skin surface at the Cz and both the mastoid (M1 and M2) were cleaned with skin abrasive, to obtain skin impedance of less than 5 kΩ for all electrodes. AgCl electrodes were used for recording of ACC. The electrodes were placed with the help of skin conduction paste and surgical plaster to secure them tightly in the respective places. Participants were made to sit on reclining chair and were instructed to relax and refrain from extraneous body movements to minimize artifacts without giving attention to the stimulus by watching a muted subtitled movie of their choice. There were three speech stimuli i.e., /sa/,/si/ and /su/ stimuli with the total duration of 350 ms (consonant duration of 120 ms and vowel duration of 230 ms) were presented with insert earphone (ER-3A, with frequency ranging from 50 Hz to 8k Hz). The testing was done binaurally with stimulus intensity of 80dBnHL. The details of the protocol for click evoked ABR and ACC are mentioned in Table 3.1.

Table 3.1: *Stimulus and recording parameter for click evoked ABR and speech evoked Acoustic Change Complex*

	Click evoked ABR	**Acoustic Change Complex**
Type of stimulus	Click (100 µs)	Speech Stimulus /sa/, /si/, /su/
Intensity	80 dBnHL	80 dBnHL
Maximum number of averages	1500	250
Repetition rate	11.1/s & 90.1/s	1.1/sec
Number of channels	2	1
Gain	100000	75,000
Band Pass filter	100-3000 Hz	1-30 Hz
Analysis Time	12 ms	900 ms
Pre Stimulus time	Nil	100 ms
Electrode Placement	Cz-non-inverting electrode M1&M2-inverting electrodes Lower forehead- Ground	Cz- non inverting electrode M1- inverting electrode M2- ground
Transducer	ER3A Insert phone	ER3A Insert phone
Ear	Monaural	Binaural
Polarity	Rarefaction	Rarefaction

3.6 Statistical Analysis

Descriptive statistical analysis to find mean and standard deviation (SD) was carried out in both the groups and across the three speech stimuli i.e., /sa/, /si/ and /su/. Further, one-way repeated measure ANOVA (mixed ANOVA) and Bornferroni pairwise comparison test was carried out to compare latency and peak-to-peak amplitude measures between the two groups and across the three stimuli. Statistical Package for Social Sciences (SPSS) Version 20.0 software was used to carry out the statistical analysis.

Chapter 4

Results

The Acoustic Change Complex (ACC) was being recorded using three different speech stimuli (/sa/, /si/ & /su/) in 17 musicians and 17 non-musicians in the age range of 18 to 30 years. The latency for P1, N1, P2, 2N1 and 2P2 and peak-to-peak amplitude for N1-P2, P2-2N1 and 2N1-2P2 were measured. The latency and amplitude values were compared among both the groups (musicians& non-musicians) and across three different speech stimuli (/sa/, /si/ & /su/). All the statistical analysis was carried out using Statistical Package for Social Sciences (SPSS), Version 20.0.

Statistical tests included were descriptive analysis, one-way repeated measure ANOVA (mixed ANOVA) and Bonferroni pair wise comparison test. Descriptive analysis was done to find out mean and standard deviation (SD) of latencies and peak-to-peak amplitude for all the parameters between musicians and non-musicians. One-way repeated measure ANOVA was carried out to compare the latencies and peak-to-peak amplitude across three different speech stimuli and between two groups. Bornferroni pairwise comparison test was done to carry out pair wise comparison between musicians and non-musicians and across the three speech stimuli (/sa/, /si/, & /su/). The individual waveform and grand mean average waveform of /sa/, /si/ and /su/ speech stimuli for musicians (A) and non-musicians (B) are mentioned as Figure 4.1 to 4.6.

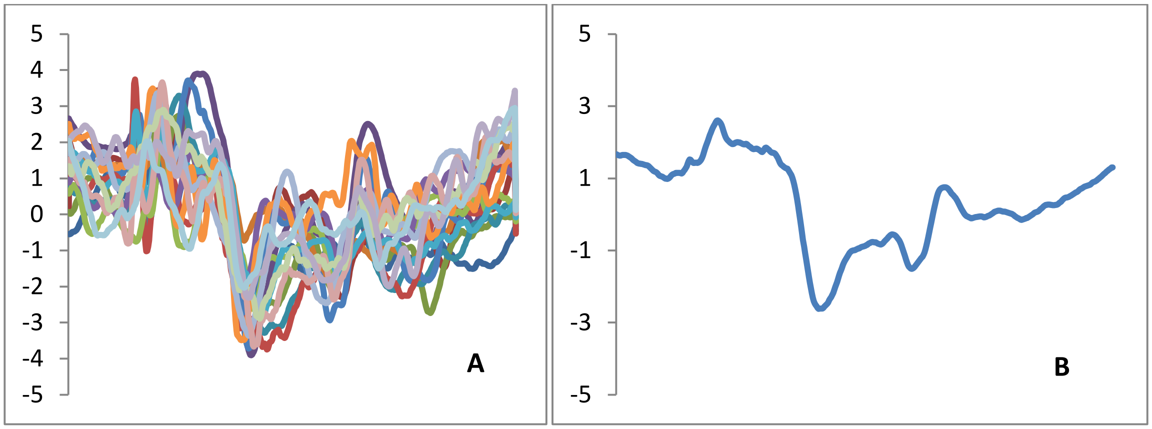

Figure 4.1: *(A) Individual waveform of /sa/ stimuli in musicians and (B) Grand mean average of /sa/ stimuli in musicians*

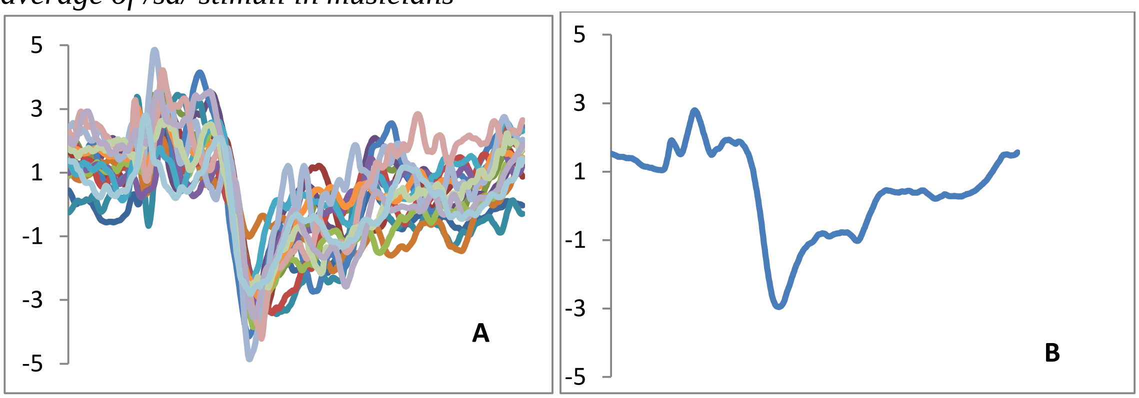

Figure 4.2: (*A) Individual waveform of /si/ stimuli in musicians and (B) Grand mean average of /si/ stimuli in musicians*

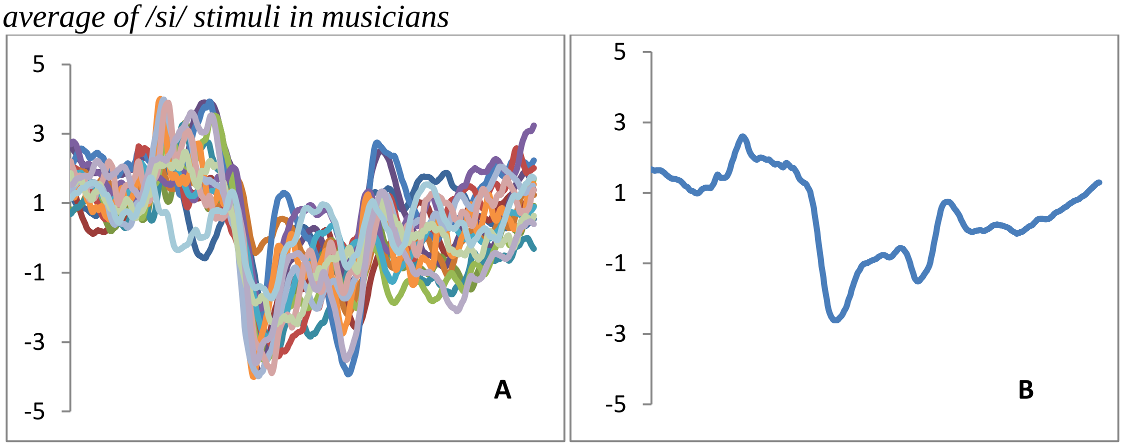

Figure 4.3: *(A) Individual waveforms of /su/ stimuli in musicians and (B) Grand mean average of /si/ stimuli in musicians*

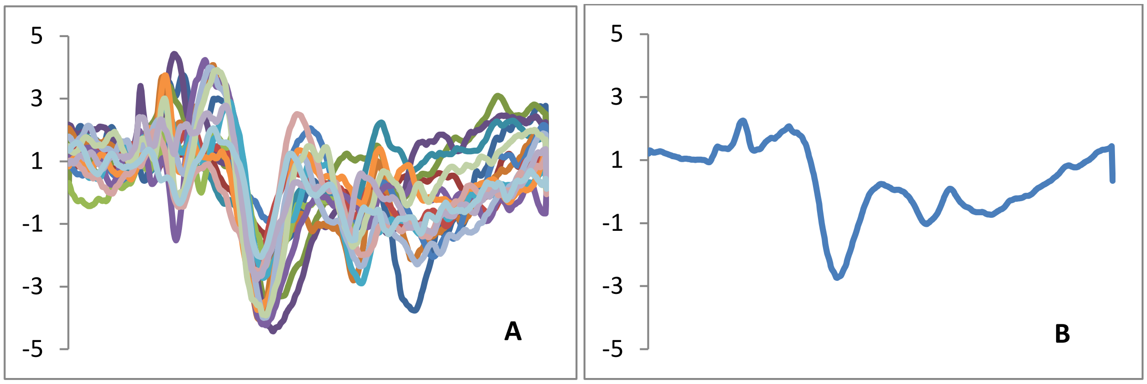

Figure 4.4: *(A) Individual waveforms of /sa/ stimuli in non-musicians and (B) Grand mean average of /sa/stimuli in non-musicians.*

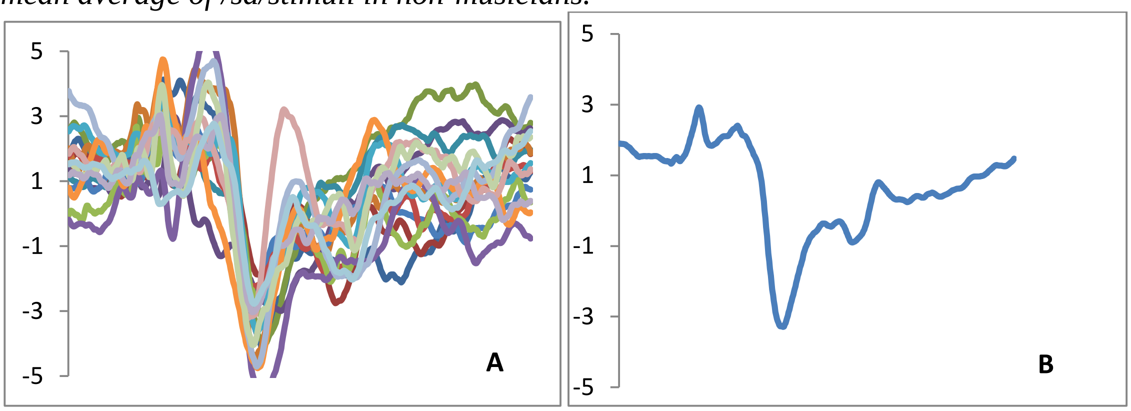

Figure 4.5: ***(****A) Individual waveforms of /si/ stimuli in non-musicians and (B) Grand mean average of /si/stimuli in non-musicians.*

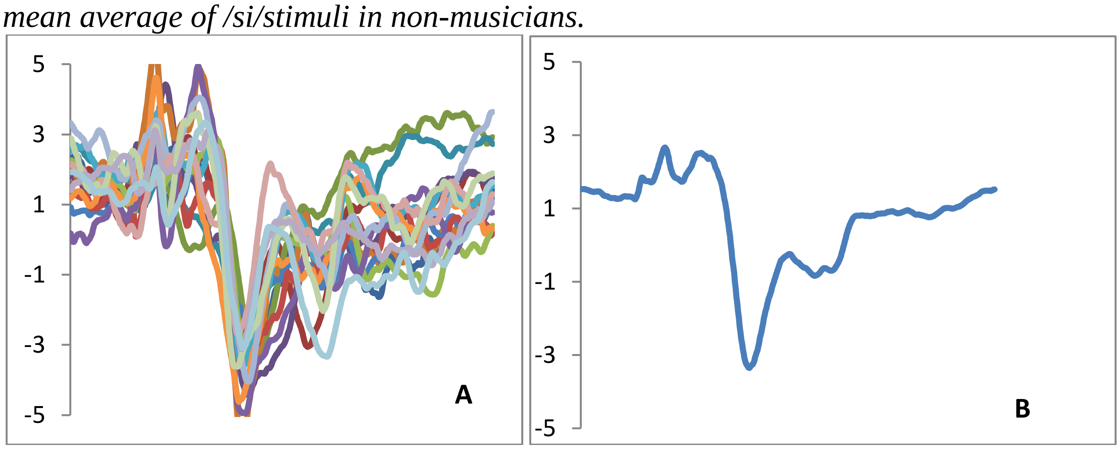

Figure 4.6: *(A) Individual waveforms of /si/ stimuli in non-musicians and (B) Grand mean average of /si/stimuli in non-musicians*

4.1 Latency measures for ACC

Mean and standard deviation (SD) of latency measures of ACC for both musicians and non-musicians for different speech stimuli are shown in Table4.1. From Table 4.1, it is observed that the latency measures for P1, N1, P2, 2N1 and 2P2 for musicians are lesser (better) than the non-musicians for all the three speech stimuli. However, SD of non-musicianswas observed to be higher as compared to the musicians. Figure 4.7 and 4.8 represents error bars of latency measures in both groups as well as for different speech stimuli respectively.

Table 4.1: *Mean and Standard Deviation (SD) of latencies in musician and non musician groups across the three stimuli*

Latency		**Musician**		**Non-Musician**	
		Mean (ms)	**SD**	**Mean(ms)**	**SD**
P1	**/sa/**	65.22	4.95	65.71	5.76
	/si/	62.45	5.22	65.98	6.43
	/su/	62.86	4.74	65.08	6.25
N1	**/sa/**	101.77	14.87	102.79	17.05
	/si/	101.15	12.24	101.58	10.11
	/su/	105.03	13.58	105.66	15.52
P2	**/sa/**	173.67	11.84	176.13	11.35
	/si/	171.93	11.89	173.65	10.40
	/su/	178.16	10.45	183.76	9.79
2N1	**/sa/**	228.48	7.95	237.52	12.48
	/si/	228.78	7.86	235.89	10.72
	/su/	229.47	8.20	240.31	12.80
2P2	**/sa/**	290.19	21.21	312.24	34.92
	/si/	293.80	31.27	313.84	25.53
	/su/	287.56	23.28	307.74	39.86

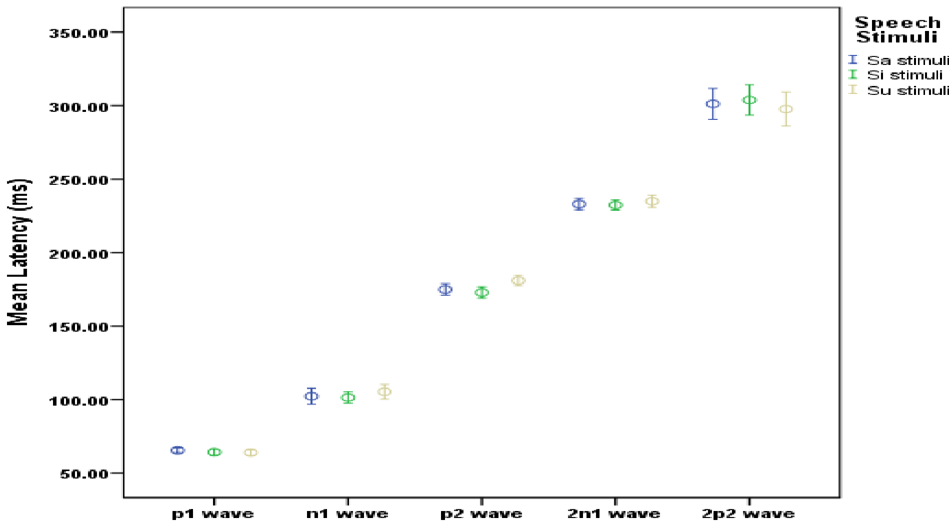

Figure 4.7: Error bars of ACC latency measures across different speech stimuli

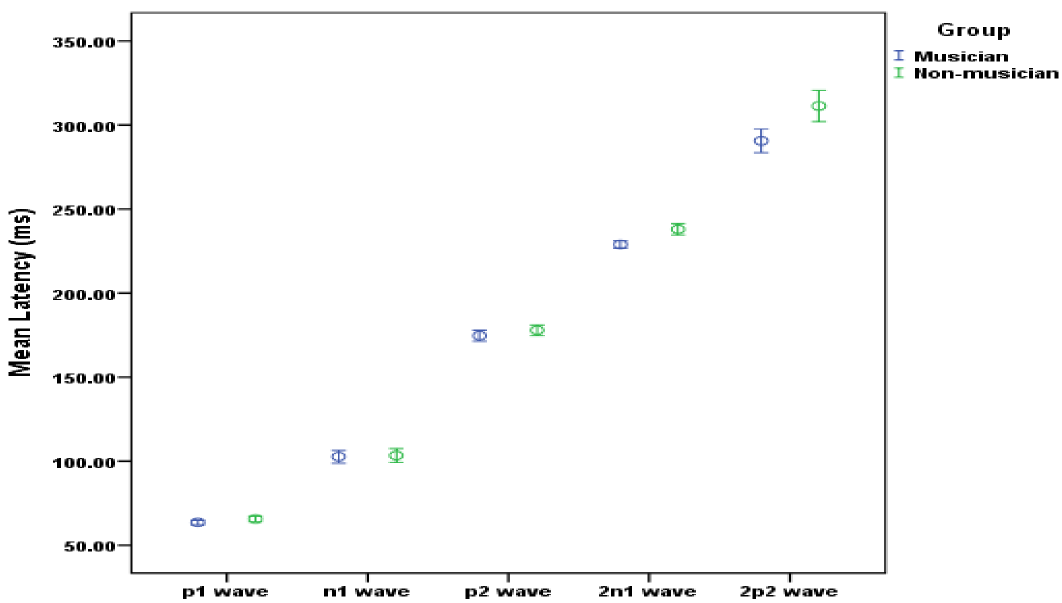

Figure 4.8: Error bars of ACC latency measures in musicians and non-musicians

One way repeated measure ANOVA (mixed ANOVA) was carried out to compare between the groups and across different speech stimuli. The results show significant main effect across the three different speech stimuli (/sa/, /si/ & /su/) for latency of P1 and P2. However, significant main effect across different speech stimuli was not being noticed for latency of N1, 2N1 and 2P2 (Table 4.2). Further, interaction of speech stimuli with groups were measured using mixed ANOVA. Results shows there were significant interaction between groups with speech stimuli only for P1 latency [F (2, 64) = 3.502; p<0.03; partial eta squared = 0.09]. However, similar interaction between groups and speech stimuli was not observed for N1[F (2,64)=0.007; p > 0.05; partial eta squared = 0.00] , P2 [F (2,64)= 0.227; p > 0.05; partial eta squared = 0.00], 2N1 [F (2,64)= 0.602; p > 0.05; partial eta squared = 0.01] and 2P2 [F (2,64)= 0.011; p > 0.05; partial eta squared = 0.00].

Table 4.2: *Main effect of speech stimuli for latency measures*

Latency	F-value	p-values	Partial eta squared
P1	F (2,64)=3.89	0.02**	0.10
N1	F (2,64)=1.33	0.27	0.04
P2	F (2,64)= 5512.75	0.00**	0.99
2N1	F (2,64)= 1.21	0.30	0.03
2P2	F (2,64)= 0.34	0.70	0.01

Comparison between musicians and non-musicians were done using one way repeated measure ANOVA. Results show significant difference between the musicians and non-musicians groups only for latency of 2N1 and 2P2. However, latency measures of P1, N1 and P2 did not shows significant differences between musicians and non-musicians (Table 4.3).

Table 4.3: *Comparison of latency measures between musicians and non-musicians*

Latency	F-value	p-values	Partial eta squared
P1	F (1,32)= 1.36	0.25	0.04
N1	F (1,32)=0.033	0.85	0.00
P2	F (1,32)=0.356	0.55	0.01
2N1	F (1,32)=9.604	0.00**	0.23
2P2	F (1,32)=13.058	0.00**	0.29

Bonferroni pairwise comparison test was done across three speech stimuli for latency parameters i.e. P1, N1, P2, 2N1, and 2N2. The results shows there were statistically significant difference between different speech stimuli for P1 latency. Similarly, significant differences were also observed between speech stimuli for P2 latency measures. However, for other latency measures i.e., N1, 2N1 and 2P2 did not show any significant differences between different speech stimuli (Table 4.4).

Table 4.4: *Outcomes of Bonferroni pair wise comparison test across speech stimuli*

Latency	Speech stimuli	**/si/**	**/su/**
P1	/sa/	S	S
	/si/		NS
N1	/sa/	NS	NS
	/si/		NS
P2	/sa/	NS	S
	/si/		S
2n1	/sa/	NS	NS
	/si/		NS
2p2	/sa/	NS	NS
	/si/		NS

Note:- S: Significant; NS:- Non-significant

4.2 Amplitude measures of ACC

Descriptive analysis of peak-to-peak amplitude was carried out to find mean and standard deviation (SD) as shown in Table 4.5. From Table 4.5, it can be inferred that peak-to-peak amplitude measures for different speech stimuli for musicians were higher (better) then non-musicians. Further, SD was relatively higher for non-musicians in comparison to musicians group. Figure 4.9 and 4.10 represents error bars of mean and SD in both groups and at different speech stimuli respectively.

Table 4.5: *Mean and Standard Deviation (SD) of amplitudes in musicians and non-musicians*

Peak-to-peak amplitude		Musicians		Non-Musicians	
		Mean(ms)	**SD**	**Mean(ms)**	**SD**
N1-P2	**/sa/**	3.21	0.99	2.25	1.21
	/si/	3.43	1.36	2.39	0.93
	/su/	2.30	0.97	2.03	0.77
P2-2N1	**/sa/**	4.85	1.10	4.66	1.57
	/si/	5.39	1.08	4.95	1.32
	/su/	4.63	1.03	4.76	1.21
2N1-2P2	**/sa/**	3.88	1.23	3.70	1.25
	/si/	4.74	1.26	4.65	1.52
	/su/	4.07	1.15	3.15	1.26

To compare the outcomes of peak-to-peak amplitude between the two groups (musicians and non-musicians) and across the three speech stimuli (/sa/, /si/ & /su/), One way repeated measures ANOVA (mixed ANOVA) was carried out. As shown in Table 4.6, there were significant main effect observed across the three speech stimuli i.e./sa/, /si/ and /su/ in peak-to-peak amplitude of N1-P2, P2-2N1, and 2N1-2P2. Further, interaction between the groups with speech stimuli were analyzed using mixed ANOVA. The results revealed no main interaction between speech stimuli with peak-to-peak amplitude measures of N1-P2 [$F(2, 64) = 2.14$; $p > 0.05$], P2-2N1[$F(2,64) = 0.88$; $p > 0.05$] and 2N1-2P2 [$F(2,64) = 1.67$; $p > 0.05$].

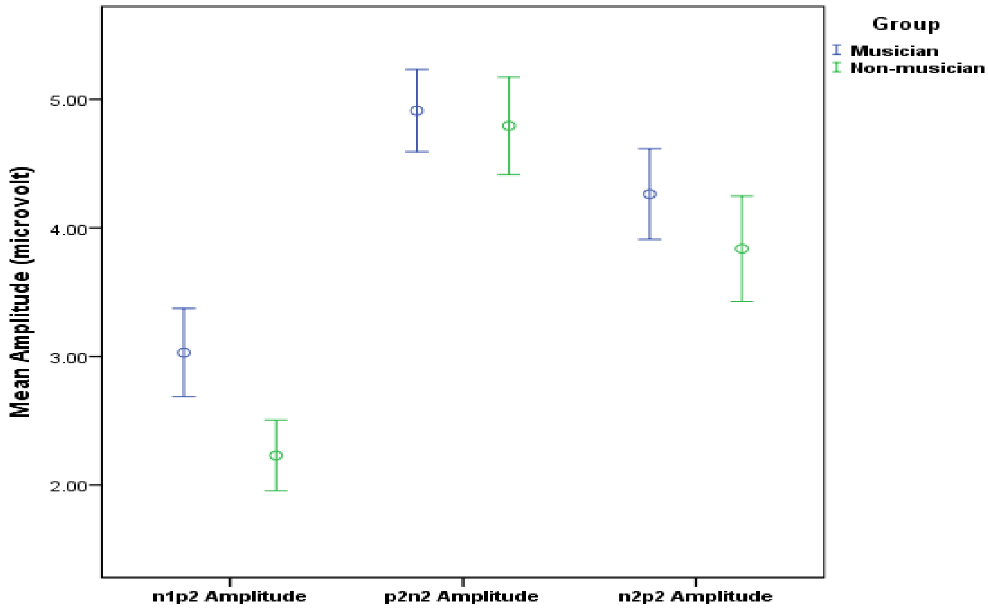

Figure 4.9: *Error bars of ACC peak-to-peak amplitude measures in musicians and non-musicians*

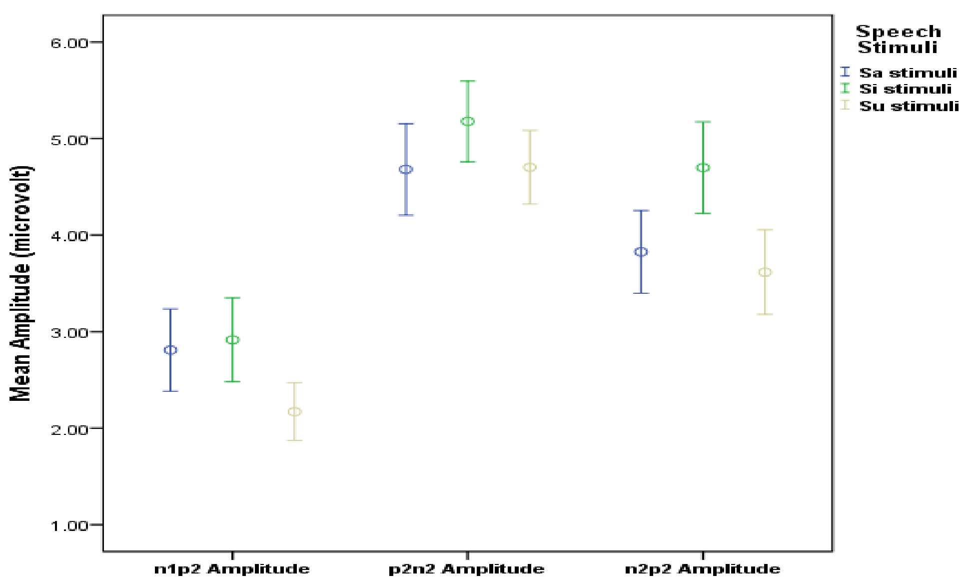

Figure 4.10: *Error bars of ACC peak-to-peak amplitude measures across different speech stimuli*

Table 4.6: *Main effect of speech stimuli for amplitude measures*

Peak-to-peak amplitude	F-value	p-values	Partial eta squared
N1-P2	F (2,64)=7.05	0.00**	0.18
P2-2N1	F (2,64)=2.98	0.05*	0.08
2N1-2P2	F (2,64)=10.88	0.00**	0.25

As shown in Table 4.7, mixed ANOVA showed significant difference between the musicians and non-musicians for peak-to-peak amplitude of N1-P2. However, peak-to-peak amplitude of P2-2N1 and 2N1-2P2 did not show significant differences between the two groups (Table 4.7).

Table 4.7: *Comparison between musicians and non-musicians for amplitude measures*

Peak-to-peak amplitude	F-value	p-values	Partial eta squared
N1-P2	F (1,32)=7.56	0.01**	0.19
P2-2N1	F(1,32)=0.23	0.62	0.00
2N1-2P2	F (1,32)=1.39	0.24	0.04

Bornferroni pairwise comparison of peak-to-peak amplitude across three different stimuli was done and mentioned in table 4.8. The pairwise comparison shows significant differences between speech stimuli for N1-P2, P2-2N1, and 2N1-2P2 amplitude.

Table 4.8: *Bornferroni pair wise comparison test across speech stimuli*

Peak-to-peak Amplitude		/si/	/su/
N1-P2	**/sa/**	**NS**	**S**
	/si/		**S**
P2-2N1	**/sa/**	**S**	**NS**
	/si/		**S**
2N1-2P2	**/sa/**	**S**	**NS**
	/si/		**NS**

Note:- S: Significant; NS:- Non-significant

Chapter 5

Discussion

The hypothesis of the study was whether there is any differences in latency and peak-to-peak amplitude in ACC in musicians and non-musicians groups. Further, it was also aimed to see whether there are any differences in terms of latency and amplitude across use of different speech stimuli (/sa/, /si/ & /su/). To access these differences acoustic change complex was being recorded using these speech stimuli in musicians and non-musicians. Further, the results of the same are discussed under following headings:

1. Findings of latency measures across groups and across speech stimuli
2. Findings of peak-to-peak amplitude measures across groups and across speech stimuli

5.1 Findings of latency measures across groups and across speech stimuli

In line with the hypothesis, the latency responses of P1, N1, P2, 2N1 and 2P2 were compared between musicians and non-musicians as well as across speech stimuli. One way repeated measure ANOVA showed significant differences in latency of 2N1 and 2P2 between musicians and non-musicians. However, across different speech stimuli, significant differences were observed only for the latency of P1 and P2. The findings is in corroboration with the study done by several researchers (Pantev et al.,1998; Tremblay, Kraus, McGee, Ponton, Otis., 2001; Atienza Cantero, & Dominguez-Marin., 2002; Shahin, Bosyak, Trainor, & Rober 2003; Kuriki, Kanda, & Hirata, 2006; Nikjeh, Lister & Frisch, 2009; Shetty & Manjula, 2012, 2013). However, few study contraindicated the present findings (Musacchia et al., 2008).

Shahin et al (2003) studied CAEP's on violinists in the age range of 22.1 to 26.5 years using musical stimuli. Result of the study showed that there were earlier peaks of P2 and N1c (radially oriented AEP) seen in instrumental musicians as compared to non-musicians. They explained the possible reason could be because of enhancement which was expressed preferentially in the right hemisphere, where there may be specialization of auditory neurons in processing of spectral pitch. The above findings were also in agreement with the study done by Kuriki et al., (2006). They studied CAEPs on individuals with minimum experience of 8 years in playing of piano instrument. The outcome of the study showed an improvement in latency of P2 peak which is amendable to be modulated by long term musical experience. Similar findings were also reported in the studies done by Tremblay et al., in 2001; Atienza et al., in 2002; and Bosnyak, Eaton, and Roberts in 2004. Latencies measures were also carried out in study done by Nikjeh et al., in 2009 using MMN on musicians in different stimulus conditions such as pure tones, harmonic tones, and speech syllable. They reported shorter MMN latencies (better) to frequency changes in pure tones, harmonic tone and speech syllable in musicians compared to non-musicians.

In contrast to the findings of the present study, Musacchia et al., (2006) studied AEPs in individuals having experience of minimum 10 years in playing musical instrument and measured evoked potentials which showed an improvement in early peaks i.e., P1 and N1. They explained it could be because of an improvement seen in auditory memory due to musical training which shapes composite (P1–N1) and pitch-specific encoding (F0) in a coordinated manner in musicians.

The differences in the latency measures of ACC when compared across different speech stimuli in present study are partly supported by the study done by Shetty and Manjula in 2012. They used speech stimuli i.e. /sa/ and /si/ in normal hearing adults and to record ACC. They noticed earlier (better) peaks for 2N1 latency of /sa/ compared to /si/. In another study done by same authors in 2013 observed hemispheric lateralization using /sa and /si/ speech stimuli. However, outcome of the study showed that the mean latencies of 2N1 and 2P2 were shorter for /sa/ than /si/ speech stimuli. As mentioned by the authors possible reason for above findings may be because of higher energy in the initial portion of /sa/ than /si/. Further, different speech sounds activate different regions in the auditory cortex due to difference in their frequency spectrum. Low-frequency sounds such as /sa/ generally activates the lateral and anterior areas of the superior surface of the temporal lobe (Pantev et al., 1998). However, the high-frequency speech sounds such as /i/ generally are represented in the medial portion of the superior surface of the temporal lobe (Woods & Alain, 2009). Since the low-frequency transition portion of /a/ in /sa/ is assumed of being elicited from the lateral and anterior portions of the cortex, the time taken to process the stimulus is lesser compared to the high-frequency transition portion of /i/ in /si/ that might have been elicited from the medial portion of the superior surface of the temporal lobe. In addition, the latencies of onset components of CAEPs are sensitive to the faster rise time, as formant transition of /sa/ stimulus is much more rapid than /si/ stimulus which results in decrease (better) in latency of /sa/ as compared to /si/.

The possible reason of not getting significant differences in latency measures of /sa/, /si/ and /su/ stimuli between the two groups in the present study could be because of musicians were trained in later stage. There were 8 out of 17 participants in experimental groups learned music at later stage. The importance of early music exposure is well explained by Pantev et al. (1998), as they pointed out the degree of cortical reorganization and enhancement of the cortical response to speech stimuli depends on the age at which musical training was started. From the anatomical viewpoint, it is noticed that musicians have more neural cell bodies (gray matter volume) in auditory, motor, and visual cortical areas of the brain (Gaser & Schlaug, 2003) and also having more axonal projections connected to both right and left hemispheres (Schlaug et al., 1995). In addition, musicians are having more activation in auditory areas such as Heschel'sgyrus (Schneider et al., 2002) and the planum temporale (Ohnishi et al., 2002) to sound. Irrespective of the specific components of the ACC, present study and earlier studies do show better performance in musician compared to non-musicians could be because of the above reasons.

5.2Findings of peak-to-peak amplitude measures between the groups and across speech stimuli

In line with the hypothesis, significant difference in peak-to-peak amplitude of N1-P2 was being observed between musicians and non-musicians whereas there was no significant difference seen for P2-2N1 and 2N1-2P2 amplitude measures. In addition, significant differences were observed in peak-to-peak amplitude of N1-P2, P2-2N1 and 2N1-2P2 across the three speech stimuli. The present findings are in agreement with the previous studies (Monaghan Metcalfe, & Ruxton., 1998; Thompson et al., 2001; Tremblay et al., 2001; Atienza et al., 2002; Shahin et.al., 2003; Bosnyak et al., 2004; Kuriki et al, 2006; Shetty & Manjula., 2012; Zuk et al., 2013). However, few studies were contraindicated the present (Shetty & Manjula, 2013).

Kuriki et al. (2006) found there is an enhancement of P2 peak in the instrumental musicians. The reason quoted by the authors were long term practice of music enhances the peak-to-peak amplitude of cortical potentials and also there might be an additional effect of the environmental factors and influence of the genotype (Monaghan et al., 1998; Thompson et al., 2001).

Significant differences seen in peak-to-peak amplitudes of N1-P2, P2-2N1 and 2N1-2P2 across the three speech stimuli is again in agreement with the studies done by Kuriki et al (2006) and Shahin et al., (2003). Further, study done by Zuk et al., in 1998 did comparison of syllable discrimination in musicians with 9 years of experience in music training. The stimuli used were /ba/- /da/ (spectral change within formant transition), /ba/-/wa/ (duration change of formant transition), and /ga/-/ka/ (change in voice onset time). Results showed musicians were having superior discrimination abilities for syllables which required better resolution of temporal cues.

The present study is also in agreement with the study done by Shetty and Manjula in 2012 in which they found that the initial portion of frication of /sa/ has higher energy and faster rise time due to which the mean peak-to-peak amplitude of N1-P2 were found larger for /sa/ as compared to the /si/ stimuli. In contrast to the present findings, study done by Shetty and Manjula in 2013 found that mean amplitudes of the onset and transition portion of ACC did not follow any trend for /sa/ or /si/. As mentioned by the authors the possible confounding variable could be a continuous variation of energy across the duration of each stimulus. Further, differences could be because of differences in groups being evaluated.

Overall, the differences in latency and amplitude measures of musician's performance in comparison to studies reported in literature could be because of small sample size and less exposure to music learning. Further, as noticed in present study there were 8 out of 17 musicians started learning music later stage. In addition, it was also observed that 3 out of 17 musicians withdrawn learning music from past 3-4 years. This could be the limitation of the study and should be kept in mind by future researchers.

Chapter 6

Summary and Conclusion

The present study aimed at finding the effect of different speech stimuli on Acoustic Change Complex (ACC) in trained musicians in comparison to non-musicians. To fulfill the above aims, there were 17 adult musicians with experience of minimum 5 years in Indian classical music (mean age of 20.23 years) participated in the study along with 17 age-matched adult with no formal training in music (mean age of 19.82 years). All the participants had normal hearing sensitivity in both ears. ACC was carried outin all the subjects to find the latency and peak-to-peak amplitude measures for the three speech stimuli /sa/, /si/ and /su/ using a standard protocol. Statistical analysis was carried out to measure the outcomes of the study.Results and discussion of the study are as follows:

6.1: Latency measures

Descriptive statistic showed earlier (better) latencies and lesser standard deviation in musicians as compared to non-musicians. Further, Mixed ANOVA showed significant difference in latency of P1 and P2 across three speech stimuli and latency of 2N1 and 2P2 between musicians and non-musicians. Bonferroni pairwise comparison shows significant difference for N1-P1, P2-2N1 and 2N1-2P2, when compared between different speech stimuli. Results of the present study revealed that musicians have earlier latencies as compared to non-musicians as there is an improvement seen in auditory memory due to musical training which shapes composite (P1–N1) and pitch-specific encoding (F0) in a co-coordinated manner. Also, CAEP are sensitive to faster rise time and because of higher energy in initial portion of /sa/ which showed a significant difference across the three speech stimuli.

6.2 Amplitude measures

Descriptive statistic showed enhanced peak-to-peak (better) latencies and lesser standard deviation in musicians as compared to non-musicians. Further, peak-to-peak amplitude of N1-P2, P2-2N1, and 2N1-2P2 were significantly different across three speech stimuli and peak-to-peak amplitude N1-P2 between musicians and non-musicians as revealed by mixed ANOVA. Bonferroni pairwise comparison shows significant difference for P1-N1, P2-2N1 and 2N1-2P2 amplitude measures across different speech stimuli. Results of present study revealed that musicians have better peak-to-peak amplitude as compared to non-musicians because of superior discrimination for syllables that required resolution of temporal cues. The study also concludes by saying that the initial portion of frication of /sa/ has higher energy and faster rise time due to which there are enhanced peak-to-peak amplitude.

Implications of the study:

As musical training shows an improvement in the auditory processing abilities and also shows neuroplastic changes inboth exogenous i.e. input-drivenand endogenous i.e. attention-dependentcomponents of auditory event-relatedpotentials (ERPs). It can help in providing cognitive development in clinical population such C(APD), Dyslexia, Learning Disability and other neurological deficit such as Parkinson’s disorder and Schizophrenia.ACC is a potential tool in assessing the speech perception ability it can be used to monitor the improvement seen in clinical population due to musical training.

Evidences also suggests that musicians experience lesser age related decline in auditory processing abilities as compared to non-musicians which can also be evaluated using cortical potentials such as ACC.

Future Research

- The study can be replicated using different variety of musicians such as instrumental musicians (violinist's, guitarist's etc.).
- ACC can also be compared between older population practicing music with age-matched individuals not involved in the musical training to access for the degenerative processes.

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