TEMPORAL RESOLUTION AND SPEECH PERCEPTION ABILITIES IN NOISE IN MRIDANGAM PLAYERS

Abhishek Saha

Register Number: 11AUD002

A Dissertation Submitted in Part Fulfillment for the Degree of

Master of Science (Audiology),

University of Mysore, Mysore.

ALL INDIA INSTITUTE OF SPEECH AND HEARING

MANASAGANGOTHRI, MYSORE-570006

MAY 2013.

Dedicated to my beloved Parents,

Brother

&

To Rajalakshmi ma'am

CERTIFICATE

This is to certify that this dissertation entitled **"Temporal Resolution and Speech Perception Abilities in Noise in Mridangam Players"** is the bonafide work submitted in part fulfillment for the Degree of Master of Science (Audiology) of the student with Registration Number: 11AUD002. 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.

Dr. S. R. Savithri

Director

All India Institute of Speech and Hearing,

Manasagangothri, Mysore- 570006.

Mysore

May, 2013

CERTIFICATE

This is to certify that this dissertation entitled **"Temporal Resolution and Speech Perception Abilities in Noise in Mridangam Players"** has been prepared under my supervision and guidance. It is also certified that this has not been submitted earlier in other University for the award of any Diploma or Degree.

Dr. K. Rajalakshmi

Guide

Professor in Audiology,

Department of Audiology,

All India Institute of Speech and Hearing,

Manasagangothri, Mysore- 570006

Mysore

May, 2013

DECLARATION

This is to certify that this Master's dissertation entitled **"Temporal Resolution and Speech Perception Abilities in Noise in Mridangam Players"** is the result of my own study under the guidance of Dr. K. Rajalakshmi, Professor in Audiology, Department of Audiology, All India Institute of Speech and Hearing, Mysore, and has not been submitted earlier in other University for the award of any Diploma or Degree.

Mysore Register No. 11AUD002.

May, 2013

ACKNOWLEDGEMENTS

My endless thanks to God Almighty, without whose blessing I wouldn't have been in this position.

First and foremost, I am grateful to **Prof. S. R. Savithri**, Director, AIISH, Mysore for allowing me to present my research proposal and letting me commence my study.

I wish to express my deepest gratitude to my excellent guide **Prof. K. Rajalakshmi** . She deserves thanks for all the endless support and instruction throughout this research. I wish to thank her for her patience, for her attention to details, and for being such a cooler than coolest person and great listener. God bless you Ma'am.

I would like to thank **Dr. Animesh Barman,** H.O.D, Dept. of Audiology, for permitting me to use the department.

I like to thank to **Prof. Asha Yathiraj** for her valuable suggestion and ideas from the beginning of my study. Thank-you ma'am .

Ms. Vasanthalakshmi, Lecturer in Biostatistics, deserve special thanks. She taught me statistical techniques which helped me a lot. Her contribution can be best noted in the fourth chapter of the dissertation.

I would like to thank **Chudamani ma'am** for calibrating the audiometer and my laptop for CD output.

I am extremely grateful to my parents and my brother **Dr. Animesh Saha, Kaberi,** and all my family members without whom my world is meaningless. The love and care you have given to me and the faith you have in me has brought me a long way. You have given me the support, inspiration, encouragement, and strength to face the challenges in life.

My special thanks to **Apoorva, Anoop sir, Nike sir, Bharat sir, Shreela mam, Prashanth sir, Arunraj sir** for helping me in my dissertation.

The list of admirable persons and friends that contributed to this dissertation is longer than can be described here. I will only mention some of them: my classmate and beloved friends: **Mr. Baljeet Rana, Mr. Hrudananda Sahu, Miss. Nisha K V, Mr. Sachidanand Sinha, Miss. Yashaswini, Mr. Bharatidasan S, Ms. Amulya P Rao, Mr. George Sebastian, Mr. Prajeesh Thomas, Mr.**

Rajkishor Mishra, Miss. Radhika Mishra, Mr. Avinash K, Mr. Madhusudarshan Reddy, Mr. Santos Dharmakar *who always motivated me during my this study.*

Thanks to all the subjects participated in my study and the people who helped me in getting the subjects.

Lastly, I want to thank from the depths of my heart to all our excellent staffs, my dear juniors, seniors and all my batch mates.

May God continued to be with us……….

TABLE OF CONTENTS

Chapter	Title	Page No.
I	Introduction	1 – 9
II	Review of Literature	10 – 23
III	Method	24 – 28
IV	Results and Discussion	29 – 38
V	Summary and Conclusion	39 – 41
	References	42 – 52

LIST OF FIGURES

Figure No.	Title	Page No.
Figure 4.1	Mean and standard deviation (SD) of Temporal Modulation Transfer Function (TMTF) for the two mridangam groups based on their experience at different modulation frequencies.	30
Figure 4.2	Mean and SD of Gap Detection Threshold (GDT) for the two mridangam groups based on their experience.	31
Figure 4.3	Mean and SD of Quick Speech-in-Noise – Kannada (QuickSIN) for the two mridangam groups based on their experience.	32
Figure 4.4	Mean and SD of TMTF for non-musician and musician groups at different modulation frequencies.	34
Figure 4.5	Mean and SD of GDT for the two groups (non-musician vs musician).	36
Figure 4.6	Mean and SD of QuickSIN for the two groups (non-musician vs musician).	37

CHAPTER I

INTRODUCTION

"Music is a moral law. It gives a soul to the universe, wings to the mind, flight to the imagination, a charm to sadness & life to everything." - *Plato*

Music is an art form whose medium is sound. It is an instrument for pleasure and enjoyment. Indian classical music is one of the oldest forms of music in the world. It is divided into the two major classes: Hindusthani (Northern Indian) and Karnatak or Carnatic (Southern Indian). Origins and fundamental concepts of both these types of music are the same. A musical instrument is a device created or adapted to make musical sounds. There are many different methods of classifying musical instruments. The most commonly used system in the west divides instruments into string instruments, woodwind instrument, brass instrument and percussion instruments.

A percussion instrument is a musical instrument that is sounded by being struck or scraped by a beater (including attached or enclosed beaters or rattles), or struck, scraped or rubbed by hand, or struck against another similar instrument. The percussion family is believed to include the oldest musical instruments. The percussion instruments are most commonly divided into two classes: Tuned percussion instruments, which produce notes with an identifiable pitch, and untuned percussion instruments, which produce notes without an identifiable pitch. It may play not only rhythm but also, melody and harmony.

The mridangam is a percussion instrument from India of ancient origin. The word "mridangam" is derived from the two Sanskrit words *mṛda* (clay or earth) and *anga* (body). It is a double-sided drum whose body is usually made using a hollowed piece of jackfruit wood about an inch thick. The two mouths or apertures of the drum are covered with goat skin leather and laced to each other with leather straps around the circumference of drum. These straps are put into a state of high tension to stretch out the circular membranes on either side of the hull, allowing them to resonate when struck. These two membranes are dissimilar in width to allow for the production of both bass and treble sounds from the same drum. The bass aperture is known as the "thoppi" or "eda bhaaga" and the smaller aperture is known as the "valanthalai" or "bala bhaaga". The smaller membrane, when struck, produces higher pitched sounds with a metallic timbre. The wider aperture produces lower pitched sounds. The goat skin covering the smaller aperture is anointed in the center with a black disk made of rice flour, ferric oxide powder and starch. This black tuning paste is known as the "satham" or "karanai" and gives the mridangam its distinct metallic timbre. It is the primary rhythmic accompaniment in a Carnatic music ensemble. It is also played in Carnatic concerts in countries outside of India, including Sri Lanka, Singapore, Malaysia, Australia, United Kingdom, Canada, and the United States. During a percussion ensemble, the mridangam is often accompanied by the ghatam, kanjira, and the morsing.

Many studies have reported that musicians have better auditory perception skills when compared to non-musicians. Also, there are many studies in literature which have documented that musical training improves basic auditory perceptual skills resulting in enhanced behavioral (Jeon & Fricke, 1997; Koelsch, Schroger, & Tervaniemi, 1999; Oxenham, Fligor, Mason, & Kidd, 2003; Tervaniemi, Just, Koelsch, Widmann, & Schorger, 2005; Micheyl, Delhommeau, Perrot, & Oxenham, 2006; Rammsayer & Altenmuller, 2006) and neurophysiological responses (Brattico, Naatanen, & Tervaniemi, 2001; Pantev et al., 2001; Schneider, Scherg & Dosch, 2002; Shahin, Bosnyak, Trainor, & Robertsm, 2003; Shahin, Roberts, & Pantev, 2007; Tervaniemi, Just, Schorger, Widmann, & Koelsch, 2005; Kuriki, Kanda, & Hirata, 2006; Kraus, Skoe, Parbery-Clark, & Ashley, 2009). Musicians life long experience in detecting melodies from background harmonies can be considered as a process analogous to speech perception in noise. Studies report that musicians had a more robust sub- cortical representation of the acoustic stimulus in the presence of noise (Kraus et al., 2009). Musical practice not only enhances the processing of music related sounds but also influences processing of other domains such as language (Marques, Moreno, & Casstr, 2007; Moreno et al., 2009; Parbery-Clark, Skoe, & Kraus, 2009; Schon, Magne, & Besson, 2004).

Musical training involves discrimination of pitch intonation, onset, offset and duration aspects of sound timing as well as the integration of multisensory cues to perceive and produce notes. Because of their musical training, musicians have learned to pay more attention to the details of the acoustic stimuli than non-musicians (Musacchia, Sams, Skoe, & Kraus, 2007). Music is a complex auditory task and musicians spend years fine tuning their skills. It is no wonder that previous research has documented neuroplasticity to musical sounds as a function of musical experience (Fujioka, Trainor, & Ross, 2005; Koelsch et al., 1999; Musacchia et al., 2007; Pantev et al., 1998; Pantev et al., 2001).

Previous studies also report that music training benefits auditory processing not only in the musical domain, but also in the processing of speech stimuli (Musacchia et al., 2007; Schon et al., 2004; Wong, Skoe, Russo, Dees, & Kraus, 2007). Consistent findings across a range of studies that use methods spanning from neurophysiology to behavior indicate that music training improves a variety of verbal and non verbal skills. These include working memory (Chan, Ho, & Cheung, 1998;

Forgeard, Winner, Norton, & Schlaug, 2008), processing of prosody and linguistic features in speech (Chandrasekaran, Krishanan, & Gandour, 2009; Wong et al., 2007), phonological skills (Forgeard et al., 2008), processing emotion in speech (Strait, Kraus, Skoe, & Ashley, 2009), auditory attention (Strait et al., 2010) and auditory stream segregation (Beauvois & Meddis, 1997). The notion of a positive functional relationship between music ability and performance on temporal information processing is also supported by the finding that musicians performed significantly better than non-musicians in detecting small time changes embedded in regular auditory sequences (Jones & Yee, 1997; Yee, Holleran, & Jones, 1994). The intention in researching the auditory processing (central), specifically the ability of temporal resolution occurred by observing the musicians and the ease with which they seem to perceive the sounds and turn them into melodies, sounds so much verbal and nonverbal. Thus, investigations were made highlighting the relationship between the auditory processing (central) and music as well as the influence of some variables as time of exposure to music, cultural factors and family.

Temporal resolution is defined as the perception of a short interval of time that each individual can discriminate between two auditory signals of about 2-3 ms. Thus, the threshold for temporal resolution is known as auditory acuity or temporal integration time limit. To accomplish this assessment, Musiek prepared Gap in Noise (GIN) test, in which the individual must perceive intervals of 2 ms to 20 ms amid the white noise (Samelli & Schochat, 2008; Musiek et al., 2005).

In contrast, studies of musicians suggest that musical training diary, used by professional musicians, can induce functional reorganization of the cerebral cortex. Therefore, the contact with music before the age of seven could contribute to the development of enhanced auditory processing (Ohnishi et el., 2001). The musicians surveyed had an increase in the left temporal plane identified by investigations of magneto encephalography. The authors concluded that musicians have better neural activation due to long-term musical training (Schalaug, 2001).

Previous research points out that, better development of Planum temporale is seen in those individuals where the musical training had begun before the age of nine. However, other studies argue that musical ability is innate and that musical training is not responsible for the improvement of Planum temporale. However, it is confirmed that there is improvement of the Planum temporale in relation to individuals who were exposed to early musical stimulus (Pantev et al., 2001). Another study by Ishll, Arashiro and Pereira (2006) shows that music has a positive influence on the development of the Planum temporale, because according to their study, subjects were exposed to musical training (singing) over four years compared to amateur musicians without professional guidance, performed better on temporal resolution through the test Random Gap Detection Threshold (RGDT).

Speech perception in noise (SPIN) is a complex task requiring the segregation of the target signal from the competing background noise. This task is further complicated by the degradation of the acoustic signal, with the noise particularly disrupting the perception of the fast spectro-temporal changes (Brandt, & Rosen, 1980), whereas children with language-based learning disabilities (Bradlow, Kraus, & Hayes, 2003; Ziegler, Pech-Georgel, George, Alario, & Lorenzi, 2005) and hearing impaired adults (Gordon-Salant & Fitzgibbons., 1995) are especially susceptible to the negative effects of background noise, musicians are less affected and demonstrate better performance for SPIN when compared to non-musicians (Parbery-Clark et al., 2009). Compared with non-musicians, musicians exhibit enhanced subcortical encoding of sounds with both faster responses and greater frequency encoding. These enhancements are not simple gain effects. Rather, musical experience selectively strengthens the underlying neural representation of sounds reflecting the interaction between cognitive and sensory factors (Kraus et al., 2009), with musicians demonstrating better encoding of complex stimuli (Wong et al., 2007) as well as behaviorally relevant acoustic features (Lee, Skoe, Kraus, & Ashley, 2009).

In order to extract the target acoustic signal, our auditory system must resolve two issues. First, there must be a process that partitions the acoustic input into separate auditory units. Second, there must be a mechanism for appropriately organizing these acoustic units over time. Auditory scene analysis is the term given to the internal process of segregating and subsequent grouping of an auditory stream (Bregman, 1990). Auditory scene analysis is based on the notion that pre-attentive processes use the Gestalt laws of organization (Koffka, 1935) physical similarity, temporal proximity, and good continuity- to group sounds. In acoustic terms, sounds with similar frequency and spatial location are more likely to be grouped together as auditory units. Indeed listeners take advantage of both frequency and spatial location cues to assist in the perception of speech in noise (SIN). Perceptual streaming, or the ability to hear two streams, is facilitated when concurrently presented complex tones are separated by as little as one semitone. For example, when asked to identify simultaneously presented vowels, performance improved when the fundamental frequencies were different (Scheffers, 1983; Assmann & Summefield, 1990). This phenomenon can help to explain why speech recognition in noise is more difficult when the target and the background speakers are of the same sex, and the fundamental frequencies of different voices are consequently closer in frequency. Even small frequency differences between speakers voice can be used as cues to aid speaker differentiation (Treisman, 1964; Brokx & Nooteboom, 1982).

The ability to properly group, represent, and store auditory units over time is fundamental to forming auditory streams and is therefore an essential aspect of SPIN. Concurrently presented auditory units may be represented as separate, parallel sensory traces that are not completely independent of each other (Fujioka et al., 2005, 2008). This not only highlights the auditory system's ability to represent simultaneously presented auditory units as both separate yet integrated sensory traces (Fujioka et al., 2005, 2008) but also support the idea that stream segregation is an active, rather than a passive process (Alain & Brenstein, 2008).

Musicians spend most of their time attending to and manipulating complex auditory signals that comprise multiple streams. In addition to processing concurrent auditory units (i.e., simultaneously occurring melodies), musicians must also analyze the vertical relationships between streams (i.e., harmony). In addition to this online auditory scene analyses musicians also hone their abilities to conceive, plan, and perform music in real time. Previous work has documented that musical training improves basic auditory perceptual skills resulting in enhanced behavioral (Jeon & Fricke, 1997; Koelsch et al., 1999; Oxenham et al., 2003; Tervaniemi et al., 2005; Rammsayer & Altemuller, 2006) and neurophysiological responses (Brattico et al., 2001; Pantev et al., 2001; Schneider et al., 2002; Tervaniemi et al., 2005; Kraus et al., 2009). Moreover, it would seem that musicians are able to use these perceptual benefits to facilitate concurrent sound segregation (Zendel & Alain, 2009). Musical training not only enhances aspects that are specific to musical perception, but these enhancements also cross over to other domains, particularly language, suggesting shared neural resources for language and music processing (Patel, 2003, 2007; Kraus & Banai, 2007; Kolesch, Schulze, & Sammler, 2008). For example, lifelong musical experience is linked to improved subcortical and cortical representations of acoustic features important for speech encoding and vocal communication (Magne, Schon, & Besson, 2006; Schon et al., 2004; Marques et al., 2007; Musacchia et al., 2007; Chandrashekaran et al., 2009; Strait et al., 2009). Likewise, musical experience has been shown to improve verbal ability (Forgeard et al., 2008); verbal working memory and verbal recall (Chan et al., 1998; Brandler & Rammsayer, 2003; Ho, Cheung, Chan, 2003; Jackobsen, Cuddy, & Kilgour, 2003). As a consequence of the musician's extensive experience with auditory stream analysis within the context of music, more honed auditory perceptual skills as well as greater working memory capacity, musicians seem well equipped to cope with the demands of adverse listening situations such as Speech in Noise.

Need for the study

Various studies have been documented in the literature on the enhanced auditory perceptual skills in trained musicians. The years of experience in the field of music plays a very important role in the enhancement of auditory perceptual skills in musicians. There are very few studies conducted in literature on the temporal resolution and speech perception abilities in trained musician considering the above fact of experience in terms of years of training and practice. There is also a dearth of literature reporting the temporal resolution and speech perception abilities in instrumental musicians especially in percussion instrument players like Mridangam players. Hence the present study needs to be carried out.

Aim of the Study

To find out the effect of musical training on temporal resolution abilities and speech perception in noise in mridangam players.

Objectives of the study

- To find out the temporal resolution abilities in trained mridangam players.
- To find out the speech perception abilities in the presence of background noise for the same group.
- To find out the effect of years of musical training on the temporal resolution abilities and speech perception in noise for the same group.
- To compare the temporal resolution abilities and speech perception in the presence of background noise between mridangam players and non musicians.

CHAPTER II

REVIEW OF LITERATURE

The following section provides a brief review of literature regarding the effect of musical training and/or practice on the different aspects of hearing, especially the temporal resolution abilities and speech perception in noise. The review has been divided into three sections mainly: 1) Effect of music training on structural/functional changes in the nervous system. 2) Effect of music training on temporal abilities 3) Effect of music training on speech perception in noise.

Effect of music training on structural and functional changes in the nervous system

Highly trained musicians exhibit anatomical, functional and event-related specializations compared to non-musicians. From an anatomical perspective, musicians have more neural cell bodies (grey matter volume) in auditory, motor and visual cortical areas of the brain (Gaser & Schlaug, 2003) and have more axonal projections that connect the right and left hemispheres (Schlaug, Norton, Overy, & Winner, 2005). Not surprisingly, professional instrumentalists, compared to amateurs or untrained controls, have more activation in auditory areas such as Heschl's gyrus (Schneider et al., 2002) and the planum temporale (Ohinshi et al., 2001) to sound. Musical training also promotes plasticity in somatosensory regions; with string players demonstrating larger areas of finger representation than untrained controls (Elbert, Pantev, Wienbruch, Rockstroh, & Taub, 1995). With regard to evoked potentials thought to arise primarily from cortical structures, musicians show enhancements of the P1-N1-P2 complex to pitch, timing, and timbre features of music, relative to non-musicians (Pantev et al., 2001).

Recent studies have suggested that playing a musical instrument "tunes neural activity peripheral to cortical structures" (Musacchia et al., 2007; Wong & Perrachione, 2007). These studies showed that evoked responses thought to arise predominantly from brainstem structures were more robust in musicians than in non-musician controls. The observed musician-related enhancements corresponded to stimulus features that may be particularly important for processing music. One such example observed with the frequency following response (FFR), which is thought to be generated primarily in the inferior colliculus and consists of phase-locked inter-spike intervals occurring at the fundamental frequency (F_0) of a sound (Hoormann, Falkenstein, Hohnsbein, & Blanke, 1992; Krishnan, Xu, Gandour, & Cariani, 2005). Because F_0 is understood to underlie the percept of pitch, this response is hypothesized to be related to the ability to accurately encode acoustic cues for pitch. Enhanced encoding of this aspect of the stimulus would clearly be beneficial to pitch perception of music. Accordingly, the previous studies demonstrated larger peak amplitude at F_0 and better pitch tracking in musicians relative to non musicians. Another example was observed with wave delta (~8ms post-acoustic onset) of the brainstem response to sound onset, which has been hypothesized to be important for encoding stimulus onset (Musacchia et al., 2007). Stimulus onset is an attribute of music important for denoting instrument attack and rhythm, and therefore it is perhaps not surprising that the authors observed earliest wave delta responses in musicians than non-musicians. More importantly, FFR and wave delta enhancement in musicians was observed with both music and speech stimuli and was largest when subject engaged multiple senses by simultaneously lip reading and watching a musician play. This suggests that while these enhancements may be motivated by music related tasks, they are pervasive and apply to other stimuli which possess those stimulus characteristics.

Musacchia, Strait and Kraus (2008) studied the relationship between evoked potentials and musical experience. They recorded simultaneous brainstem and cortical evoked potentials (EP) in musicians and non-musician controls. Because previous research showed that musician related effects extend to speech and multi-sensory stimuli, the speech syllable /da/ was presented in three conditions: when subjects listened to auditory sound alone, when the subjects simultaneously watched a video of a male speaker saying /da/ and when they viewed the video alone. The analysis focused on comparing measures of the speech evoked brainstem response that have been previously reported as enhanced in musicians with well established measurements of cortical activity (e.g., P1-N1-P2 complex). The first picture that emerged from the data was that recent musical training improves one's auditory memory and shapes composite (P1-N1) and pitch encoding (F_0) in a co-coordinated manner. The EP and behavior correlations suggest that complex auditory task performance is related to the strength of the P1-N1 response. The instrumental musicians performed better in the behavioral tests and had steeper P1-N1 slopes than non-musicians. However, it was not only the individual tests and measures that were music related. Musicians had a statistically stronger correlation between this set of brain and behavior measures than non-musicians. While it is well known that trained musicians outperform untrained musicians and have more robust evoked-potentials than non-musicians, they showed that the accord, or relationship, between brain and behavior is also improved in musicians.

In previous studies, musicians have been used as a model for experience induced plasticity, which is known to be expressed in AEPs in adults (Trembly, Kraus, McGee, Ponton, & Otis, 2001). Shahin et al. (2003) compared AEPs evoked by violin and piano tones (A3 and C3, American notation) and pure tones matched in fundamental frequency to the musical tone in young 4 to 5 year old children with age matched non-musicians children. The aim of the study was to assess whether AEP components are sensitive to musical experience at this age and, if so, which components are affected. Before conducting the main study AEP responses in independent cohorts of non-musician children between 4 and 15 year-old musically experienced children were compared with musically less experienced children. Furthermore, the P2 enhancement was specific to the instrument of practice. Thus AEPs differ between the musical and control children as young as 4 years of age, and the differences reflect specific musical experience. Comparison of piano-evoked N1 and P2 in their 4 to 5 year-old musicians (most of whom were pianists) to cross sectional findings suggest that musical experience may have advanced the developmental trajectory for sounds of the instrument of training.

Several studies have shown differences between the brain of adult musicians and non-musicians. For example, structural MRI studies indicate differences in gray matter between musicians and non-musicians in motor, auditory, and visual brain regions (Gaser & Schlaugal, 2003). Heschl’s gyrus, containing primary auditory area, was found to be larger in musicians than non-musicians and its size correlated with musical proficiency (Schneider et al., 2002). Furthermore, the left planum temporale, which is important for the processing of complex sounds, is relatively larger than the right planum temporale in professional musicians, especially those with absolute pitch (Schlaug, 2001). With respect to the integrity of directionality of organized neural fibers, white matter tracts also appear to differ between pianists and non-musicians, particularly in a pathway from primary motor cortex to the spinal cord and in a region near Broca's area, which is important for complex aspects of language and music processing.

At a functional level, the brain responses of adult musicians and non-musicians also differ as measured by EEG and MEG. For example, some event related potential responses from auditory cortical areas are larger in musicians compared to non-musicians such as N1 occurring at about 100 ms after stimulus onset, N1c, occurring at about 140 ms and larger in the right hemisphere, and P2, occurring at about 170 ms after stimulus onset (Pantev et al., 1998; Shahin et al., 2003). For a sequential stimuli, occasional wrong notes in a short melody that is repeated in different keys (i.e., starting on different notes) from trial to trial, elicit frontally negative event-related potential called mismatch negativity (MMN). While MMN to such melodic changes is present in both musicians and non musicians, it is much larger in musicians (Fujioka et al., 2004). In terms of polyphonic music, changed notes in either of the simultaneous melodies elicit MMN responses that are larger in musicians than non-musicians (Fijioka et al., 2005). Errors in one chord of a chord sequence produce an early right anterior negativity that is also larger in musicians than in non-musicians (Koelsch et al., 2002).

Effect of music training on temporal abilities

Rammsayer and Altenmuller (2006) compared the temporal information processing in musicians and non-musicians. The study was characterized by comparison between two groups, 36 academically trained musicians and 36 nonmusicians. Seven different auditory temporal tasks performed to check temporal acuity and these are auditory fusion, rhythm perception, and three temporal discrimination tasks. It was found that superior temporal acuity for musicians compared to non-musicians on auditory fusion, rhythm perception, temporal discrimination of very brief filled and empty intervals in the range of milliseconds, and temporal discrimination of filled intervals in the range of seconds.

Monteiro, Nascimento, Soares and Ferreira (2010) compared the temporal resolution abilities in musicians and non-musicians. The study was characterized by comparing between two groups, one consisting of 20 musicians and other 20 non musicians matched for age and education underwent audiological evaluation. Gap in Noise (GIN) was conducted to evaluate the temporal resolution. They found that GIN test performance was not statistically significant difference between two groups.

Thomas and Rajalakshmi (2011) studied the temporal resolution abilities in trained Carnatic vocal musician as a function of years of musical training and practice. They considered 20 professionally trained Carnatic vocal musicians for the study, who were classified into 4 groups; each group consisting of 5 members, based on their years of experience in terms of training and/or practice. To observe temporal resolution abilities Temporal Modulation Transfer Function (TMTF) and Gap Detection Threshold (GDT) tests were carried out. They found that temporal resolution abilities were better in trained Carnatic vocal musician than in non-musicians. The results of TMTF and GDT values showed that the temporal resolution abilities become better with increased musical experience of the musicians.

Rajalakshmi and Bhushan (2012) compared temporal resolution abilities in children born in families with musical background and children born in families without musical background. The study compared the performance between control groups and experimental groups. Control group consisted of two subgroups, one consisted of 10 children born in non-musical background with no formal musical training in the age range of 12-16 years and other consisted of 10 children born in non-musical background but trained in music in the age range of 12-16 years.

Experimental group also consisted of two subgroups, one consisting of 10 age matched children born with musical background but not trained in music and other 10 age matched children born with musical background and also undergoing formal musical training. To check temporal resolution abilities TMTF (at 6 different frequencies) and GDT tests were carried out. They found that the temporal resolution abilities were better in children with musical training than compared to children without musical training. Musical training as a factor has contributed to better performance, whether or otherwise of the family background. Secondly, the family background with musical training has shaped the auditory processing skills to the finest level. In the context of no family background, musical training has yielded good performance. Finally in the absence of family background and musical training the auditory processing skills have not shown significant differences.

Effect of music training on perception in noise

Musicians, as a consequence of training that requires consistent practice, online manipulation, and monitoring of their instrument, are experts in extracting relevant signals from the complex sounds cape (e.g., the sound of their own instrument in an orchestra). Literature shows that the effect of musical experience is transferred on the skills that sub serve successful perception of speech in noise. A recent study found a distinct speech in noise advantage for musicians, as measured by standardized tests of hearing in noise [Hearing in- noise test (HINT); Quick Speech-in-Noise (QuickSIN)] (Parbery-Clark et al., 2009). Across all participants, the number of years of consistent practice with a musical instrument correlated strongly with performance on QuickSIN, auditory working memory and frequency discrimination. These correlations strongly suggest that practice fine tunes cognitive and sensory abilities, leading to an overall advantage for speech perception in noise in musicians. The results from the study suggest that musical experience enhances the ability to hear speech in challenging listening environments. SPIN is a complex task requiring perceptual cue detection, stream segregation, and working memory. Musicians performed better than non-musicians in conditions where the target and the background noise were presented from the same source, meaning parsing was more reliant on the acoustic cues present in the stream.

In order to find the effect of musical experience on the neural representation of speech in noise, Parbery-clark et al. (2009) compared sub-cortical neurophysiological responses to speech in quiet and noise in a group of highly trained musicians and non-musician controls. Speech evoked auditory responses were done with speech syllable /da/ on all subjects. The results indicated that musicians exhibited more robust speech evoked auditory brainstem responses in background noise. Musicians had earlier response onset timing, as well as greater phase locking to the temporal waveform and stimulus harmonics, than non-musicians. They also found that earlier responses timing and more robust brainstem responses to speech in background noise were both related to better speech in noise perception as measured through Hearing in- noise test. They concluded that musical experience resulted in more robust subcortical representation of speech in the presence of background noise, which may contribute to musician's behavioral advantages for speech in noise perception.

Musicians also exhibited more robust responses to the steady state portion of the stimulus in the presence of background noise. By calculating the degree of similarity between stimulus waveform and the subcortical representation of the speech sound, it was found that musicians had higher stimulus to response correlation which is indicative of more precise neural transcription of stimulus features. One possible explanation for this musician enhancement in noise may be based on Hebbian principle, which posits that the association between neurons that are simultaneously active are strengthened and those that are not subsequently weakened (Hebb, 1949). Given the present results it is speculated that extensive musical training may lead to better musical coherence. This strengthening of the underlying neural circuitry would lead to a better bottom-up; feed forward representation of the signal. It is well documented that the auditory cortex sharpens the subcortical sensory representations of sounds through the enhancement of the target signal and the suppression of irrelevant competing background noise via the efferent system (Zhang & Suga, 1997). The musician's use of fine grained acoustic information and lifelong experience with parsing simultaneously occurring melodic lines may refine the neural code in a top-down manner such that relevant acoustic features are enhanced early in the sensory system. This enhanced encoding improves the subcortical signal quality, resulting in more robust representation of the target acoustic signal in noise.

The improved stimulus to response correlation in the noise condition was related to greater neural representation of the stimulus harmonics (H2 – H10) but not to the fundamental frequency in noise. Musicians, through the course of their training, spend hours producing, manipulating, and attending to musical sounds that are spectrally rich. The spectral complexity of music is partly attributable to presence and relative strength of harmonics as well as the change in harmonics over time. Musicians have enhanced cortical responses to their primary instrument suggesting that their listening and training experience modulates the neural responses to specific timber (Pantev et al., 2001). Likewise, musicians demonstrate greater sensitivity to timber difference and harmonics changes within a complex tone (Koelsch et al., 1999; Musacchia et al., 2008; Zendel & Alain, 2009).

Thomas and Rajalakshmi (2011) studied the speech perception abilities in the presence of background noise in trained Carnatic vocal musicians over the years of musical training and practice. Speech perception in noise (SPIN) test was carried out at different signal to noise ratios (SNRs). They found that the ability to perceive speech in the presence of background noise was better in trained Carnatic vocal musician than non-musicians. But the result of the speech perception in noise were statistically not significant when the musicians were compared across their experience, though the scores were better in experienced musicians when compared to the musicians with less experience.

Rajalakshmi and Bhushan (2012) compared speech perception in noise abilities in children born in families with musical background and children born in families without musical background. To check speech perception in noise Quick Speech-in-Noise in Kannada (Avinash, Methi, & Kumar, 2009) test was carried out on 20 children with musical background and 20 children without musical background. They found that the ability to perceive speech in the presence of noise was better in children with musical training than compared to children without musical training.

Janet and Yathiraj (2003) evaluated whether there is any enhancement of auditory perceptual processes in children who are trained in music using measures such as speech-in-noise test. They compared between two groups, one consisting of 15 normal hearing children in the age range of 6 to 12 years who are trained in music and other group consisted of 15 age and sex matched children who are not trained in music. They found that the speech-in-noise scores of musically trained children were better and they suggested that the enhancement in speech-in-noise scores seen in musically trained children could be due to the training to listen to the melody played while a constant rhythm is played in the background.

The research done on musicians has revealed the advantages in different aspects when compared to non-musicians. Studies have reported that the music training not only improves the skills related to music perception, but also other different aspects like improvement in language related skills, emotional and cognitive processes.

Effect of Music Training on Language Related Skills

The domains of music and language share many features, the most direct being that both exploit changes in pitch patterns to convey information. Music uses pitch contours and intervals to communicate melodies and tone centers. Pitch patterns in speech convey prosodic information; listeners use prosodic cues to identify indexical information, i.e., information about the speaker's intention as well as emotion and other social factors. Further, in tonal languages, changes in pitch are used lexically; that is, in differentiating between words. A significant body of research has focused on the extent to which musical experience provides benefits in language abilities; the results unambiguously suggest that musicians show enhanced processing of prosodic and linguistic pitch. Musicians show an enhanced ability to detect subtle incongruity in prosodic pitch as well as consistent neural differences relative to nonmusicians (Besson, Schon, Moreno, Santos, & Magne, 2007; Magne et al., 2006). Differences between musicians and nonmusicians show up even during pre-attentive stages of auditory processing (Chandrasekaran et al., 2009; Musacchia et al., 2007; Wong & Perrachione, 2007). Frequency following responses (FFR), which ensemble neural responses originating at the auditory brainstem that reflect phase-locking to stimulus features, were recorded from musicians and non-musicians who were listening to the speech syllable /da/ (Musacchia et al., 2007). Relative to non-musicians, musicians showed more robust encoding of timing and pitch features in the speech signal at the level of the brainstem. Using FFR as an index, musicians showed a superior representation of dynamic pitch contours, as reflected by improved pitch tracking accuracy at the level of brainstem (Wong et al., 2007). The ability to track non-native pitch contours correlated positively with number of years of musical training, suggesting that it was musical experiences that improved lower level representation of non-native pitch. Musicians showed superior cortical representation of linguistic pitch in a non-native language relative to non musicians (Chandrasekaran et al., 2009). In this study, native tone-language speakers showed the strongest representation of pitch, suggesting that the context of long term training matters. From a functional perspective, the enhanced cortical and brainstem representations are indeed relevant. Musicians showed a superior propensity to use pitch in lexical contexts during a language learning task, relative to non-musicians (Wong & Perrachione, 2007). Musician’s enhancement is not just restricted to pitch features. Studies also have demonstrated that musicians show superior brainstem representation of timing and harmonic structure in speech, features that are important for differentiating speech sounds (Musacchia et al., 2007; Parbery-Clark et al., 2009). Taken together these studies demonstrate that musicians show a distinct advantage in the early auditory processing of speech features.

In an earlier study, Chan et al. (1998) showed that participants with music training exhibited superior verbal memory relative to non-musicians, as indicated by greater number of words recalled in a list learning task. Children who received instrumental training not only showed enhanced processing of skills related to music, but also showed enhanced vocabulary relative to untrained controls (Forgeard et al., 2008) in typically developing children with normal reading ability, musical discrimination skills significantly predicted phonological and reading skills (Forgeard et al., 2008).

Effect of music training on emotional and cognitive processing

Perception of emotion in speech and music relies on shared acoustic and neural mechanisms (Nair, Large, Steinberg, & Kelso, 2002) suggesting that extensive experience in one domain may lend perceptual benefits to the other., Strait et al. (2009) demonstrated increased neural efficiency in musicians by examining the subcortical encoding of a complex, emotionally salient stimulus (a child's cry) as a function of music experience. They aimed to provide a biological basis for musician's enhanced perception of emotion in speech by investigating the contribution of subcortical mechanisms to the processing of vocally communicated emotional states. 30 musicians were included in the study, who were classified into 2 groups based on 2 criteria: musicians by onset age (Mus Age) and musicians by years (Mus Yrs). Mus Age subjects had begun musical training at or before age of 7 years, whereas Mus Yrs subjects had received more than 10 years of consistent musical experience. Integrity of auditory brainstem was assessed using auditory brainstem responses with both click and speech (/da/). The authors suggested that musical experience has more pervasive domain-general effects on the auditory system than previously documented, resulting in fine neural timing to acoustic features important for vocal communication. The results thus provided initial biologic involvement of subcortical mechanisms in the auditory processing of communicated states of emotion.

Relative to non-musicians, musicians showed superior encoding of the most acoustically complex portion of the emotional stimuli, consistent with behavioral studies demonstrating enhanced emotional perception in musicians (Thompson, Schellenberg, & Husain, 2004). Similarly musicians also demonstrated selective neural enhancement of the upper note of musical chords (Lee et al., 2009). Music training also has been shown to improve working memory (Forgeard et al., 2008; Jakobson, Lewycky, Kilgour, & Stoesz, 2008; Parbery-Clark et al., 2009) and executive function abilities (Bialystok & DePape, 2009). Musicians are also significantly better than non-musicians in auditory stream segregation, presumably due to their music training (Beauvois & Meddis, 1997; Zendel & Alain, 2009).

Hence, to observe the influence of musical training on the auditory abilities of mridangam players the present study was undertaken.

CHAPTER III

METHOD

The present study aimed to find out the effect of musical training on temporal resolution abilities and speech perception in noise in mridangam players using Temporal Modulation Transfer Function (TMTF), Gap Detection Test (GDT) and Quick Speech Perception in Noise – Kannada, tests.

Participants

A total of 20 professionally trained mridangam players in the age range of 18 to 55 years were included in the study. The musicians were classified into 2 groups; each group consisted of 10 members, based on their years of experience in terms of training and/or practice. Group 3 consisted of 20 age matched normal hearing non- musicians.

Group 1: Mridangam players who had training/ practice for 5 to 10 years.

Group 2: Mridangam players who had training/ practice for 15 years and above.

Group 3: 20 Normal hearing non musicians aged between 18 to 55 years.

An informal questionnaire was administered to all the participants, in order to get the information regarding their experience in the musical field.

Participants Selection Criteria.

- All the subjects with normal air conduction thresholds (<15 dB HL) at all octave frequencies from 250 Hz to 8000 Hz and bone conduction thresholds (<15 dB HL) at octave frequencies from 250 Hz to 4000 Hz.
- Normal middle ear function (‘A’ type tympanogram for 226 Hz probe tone with normal acoustic reflexes in both ears).

- Speech Recognition Threshold of ±12 dB with reference to pure tone average (PTA) (0.5, 1 and 2 KHz).
- Speech Identification Score of > 90% at 40 dB SL with reference to speech recognition threshold (SRT) in both ears.
- No indication of Retrocochlear Pathology (RCP).
- No history of neurological or otological problem.
- No illness on the day of testing.
- All participants were native Kannada speakers.
- All musicians should have training in Carnatic music for minimum of 5 years.
- All mridangam players were presently performing or obtaining training.
- For control group, individuals with no formal music training/experience were considered who had normal hearing.

Environment

All the testing were carried out in a sound treated double room situation as per the standards of ANSI S3.1 (1991).

Instrumentation

The following instruments were used in the present study:

1. Orbiter 922 (Madsen Electronics, Denmark), two channel audiometer, calibrated as per ISO 389, with supra-aural headphones (Telephonics TDH-39) housed with MX-41/AR ear cushions with audio cups and a bone vibrator (Radio ear B71) were used to assess the pure tone threshold.
2. GSI Tympstar (Grason-Stadler Inc. USA) middle ear analyzer was used for tympanometry and reflexometry.
3. A laptop (Acer Aspire 5750) was used to deliver the stimulus for Gap Detection Test (GDT), Temporal Modulation Transfer Function (TMTF) and Quick Speech Perception in Noise – Kannada.

Stimuli

- Stimuli for GDT & TMTF were generated through psychoacoustic toolbox module run under Matlab R2010b software.
- Quick Speech in Noise test in Kannada developed by Avinash, Methi & Kumar (2009) was utilized to assess the speech perception in noise.

Procedure

Pure Tone Audiometry.

Air conduction thresholds for octave frequencies from 250 Hz to 8000 Hz and bone conduction thresholds for octave frequencies from 250 Hz to 4000 Hz were obtained using the modified Hughson-Westlake procedure (Carhart & Jerger, 1959).

Speech Audiometry.

Kannada Spondee words (Rajashekar, & Vyasamurthy, 1976) were used to obtain the SRT from both the ears. A set of 3 spondees were presented at 20 dB SL with reference to PTA and the minimum level at which the subject correctly identified 2 out of 3 spondees were considered as SRT.

Speech identification scores in quiet for both ears were obtained with Kannada Phonetically Balanced (PB) words (Yathiraj & Vijayalakshmi, 2005). PB words, recorded in the voice of a typical Kannada female speaker were presented to both ears separately at 40 dB SL with reference to SRT. A total of 25 words were presented to each ear separately. Each word was given a score of 4% and the speech identification scores for each ear separately were calculated in percentage.

Immittance Audiometry.

Immittance Audiometry was carried out with GSI Tympstar (Grason-Stadler Inc. USA) middle ear analyser using 226 Hz probe frequency. Ipsilateral and Contralateral reflexes were measured for 500 Hz, 1000 Hz, 2000 Hz, and 4000 Hz.

Temporal Modulation Transfer Function (TMTF).

Two stimuli, unmodulated white noise and sinusoidally amplitude modulated (SAM) white noise of 500 ms duration, with a ramp of 20 ms were used. The stimuli was generated using a 32 bit digital to analog converter with a sampling frequency of 44.1 KHz and were low pass filtered with a cut-off frequency of 220 Hz. The Modulated signal was derived by multiplying the white noise by a dc-shifted sine wave. The depth of modulation was controlled by varying the amplitude of modulating sine wave. Modulation depth was varied between 0 to -30 dB (where 0 dB is equal to 100% modulation depth and -30 dB is equal to 0% modulation). Six different modulation frequencies were used (4 Hz, 8 Hz, 16 Hz, 32 Hz, 64 Hz, & 128 Hz).

The stimuli were presented at 40 dB SL (with reference to PTA) or at comfortable level. The stimuli were presented to the participants through headphones binaurally. The subjects' task was to discriminate between modulated and the unmodulated noise till the smallest modulation depth could be detected.

Three interval alternate forced choice method (3IAFC) was used. On each trial, un-modulated and modulated stimuli were successively presented with an inter-stimulus interval of 500 ms. Modulation depth was converted into decibels [20 log 10(m), where 'm' refers to the depth of modulation]. A step size of 4 dB was used initially and then reduced to 2 dB after two reversals. This procedure provides an estimate of the value of amplitude modulation necessary for 70.7 % estimate of correct responses (Levitt, 1971). The mean of eight reversals in a block of 14 will be taken as threshold.

Gap Detection Threshold (GDT).

Gap detection test consisted of a standard stimulus of 750 ms duration Gaussian noise with a silence of standard duration placed at its temporal center. The variable stimulus had variable gap duration and the length of its gap was changed as a function of the subject's performance. All noises had a 0.5 ms cosine ramp at both onset and offset. Three Interval Alternate Forced Choice Method (3IAFC) method was used to obtain the gap detection threshold. It consisted of three blocks of white noise, one of which contained gaps of variable duration. The subjects' task was to identify the gap and to detect which block of noise was having the gap in it. The presentation level of the stimulus was 40 dB SL (with reference to PTA) or most comfortable level. Each time when the subject detected the gap embedded in noise correctly, the size of the gap was reduced and test was continued till the subject could trace the smallest gap. The minimum gap that the subject detected was considered as the gap detection threshold. The gap detection thresholds were obtained for both the groups.

Quick Speech-in-Noise – Kannada.

Quick Speech-in-Noise - Kannada (Avinash, Methi & Kumar, 2009) was done using 60 sentences based on the subjects rating of predictability. 60 sentences which were distributed in 12 lists with 7 sentences in each list were used. Sentences were randomly divided into different lists. Some of the sentences were used in more than one list. These sentences were recorded by a native male Kannada speaker using the Pratt software (Boersma & Weenink, 2005).

An eight talker speech babble noise was used to generate sentences with different SNRs. In each list first sentence was at +20 dB SNR and SNR was reduced in 5 dB steps for the subsequent sentences. Thus in each list, first sentence was at +20 dB SNR, second sentence was at +15 dB SNR, third sentence was at +10 dB SNR, fourth sentence was at +5 dB SNR, fifth sentence was at 0 dB SNR, sixth sentence was at -5 dB SNR and last sentence was at -10 dB SNR. These SNRs encompass the range of normal to severely impaired performance in noise. Sentences used are high probability items for which the key words are somewhat predictable from the context. Each sentence has five key words that are scored as correct/incorrect. These sentences were presented at 70 dB HL through a personal computer. The listener's task was to repeat the sentences presented and each correctly repeated keyword was awarded one point for a total possible score of 35 points per list. To calculate SNR at which 50% scores are obtained, the formula given below as recommended by Avinash Methi, and Kumar (2009) was used.

SNR at which 50% scores are obtained = 22.5 - (total words correct)

CHAPTER IV

RESULTS AND DISCUSSION

The present study aimed to compare the temporal resolution abilities and speech perception in noise in Carnatic Mridangam players across their years of experience. The temporal resolution abilities were measured using Temporal Modulation Transfer Function (TMTF) and Gap Detection Threshold (GDT) test. Temporal Modulation Transfer Function was tested for six different modulation frequencies (4 Hz, 8 Hz, 16 Hz, 32 Hz, 64 Hz & 128 Hz) binaurally. Gap Detection threshold was also estimated binaurally. Quick Speech Perception in Noise – Kannada was obtained binaurally. A total of 20 trained Carnatic Mridangam players participated in the study, who were classified into 2groups based on their experience or training. Each group consisted of 10 subjects. The data were appropriately tabulated and statistically analyzed using Statistical Product and Service Solutions (SPSS) Version 17 software.

The following analyses were carried out:

1. Descriptive statistics (mean and standard deviation) were obtained for different parameters of the three tests.
2. Mixed analysis of variance (ANOVA) was administered to compare within mridangam players group based on experience and across musicians and non-musicians groups for Temporal Modulation Transfer Function (TMTF) test.
3. A repeated measure ANOVA was administered for comparisons of frequencies within groups as independent factor.

4. Bonferroni was administered for pair wise comparisons of frequencies.

5. Multivariate analysis of variance (MANOVA) was administered for the comparisons of experience within Mridangam players group within each frequency and across musician and non-musician groups. It was also administered to compare within Mridangam players group based on experience and comparison on musicians and non-musicians for GDT and Quick Speech Perception in Noise tests.

Temporal Resolution

Temporal Modulation Transfer Function:

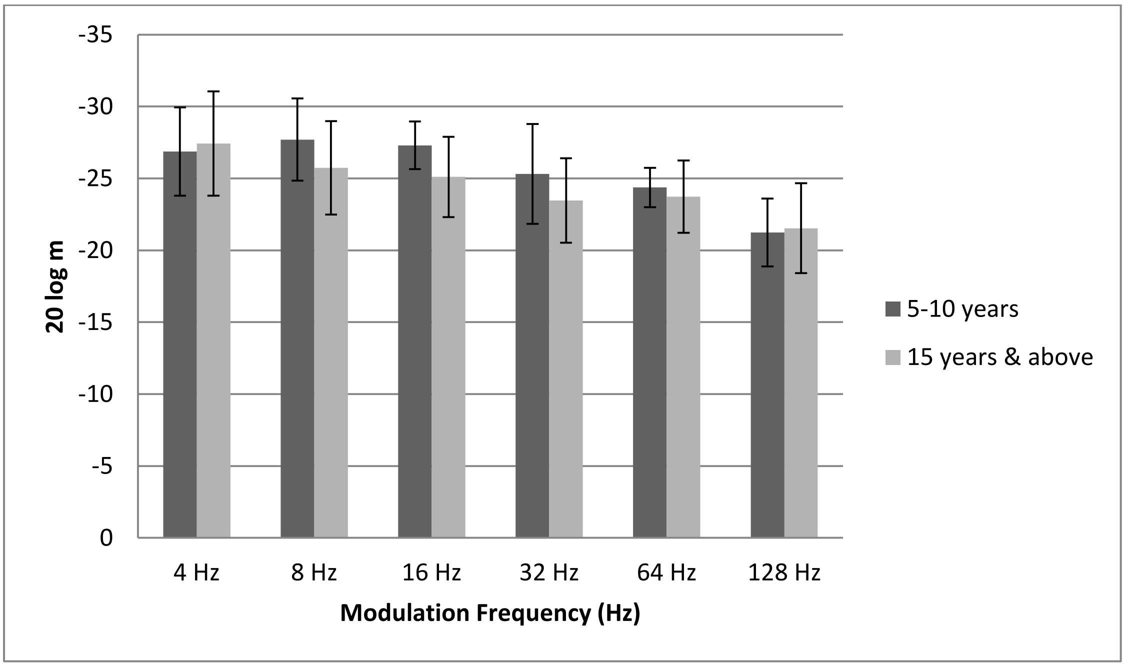

Figure 4.1. Mean and standard deviation (SD) of TMTF for the two mridangam groups based on their experience at different modulation frequencies

Temporal modulation transfer function was measured for 6 different modulation frequencies (4 Hz, 8Hz, 16 Hz, 32 Hz, 64 Hz and 128 Hz) binaurally, for two mridangam players groups. Figure 4.1 shows the mean & SD of the TMTF of all the six modulation frequencies for two mridangam players groups. Different modulation frequencies (in Hz) are represented in the abscissa and the modulation detection thresholds or modulation depths (as 20 log m) are represented in the ordinate.

Mixed ANOVA was done to compare TMTF between group 1 and group 2 based on their experience. Results revealed statistically no significant difference [F (1, 18) = 0.93, p>0.05] between both the groups based on experience. MANOVA was done for comparison of experience within group within each frequency. Results revealed statistically no significant difference based on experience within group for each frequency.

Gap Detection Threshold:

Gap detection threshold (GDT) test was administered binaurally to find the minimum temporal gap, the subject could identify. GDT test was done for both mridangam players groups based on experience.

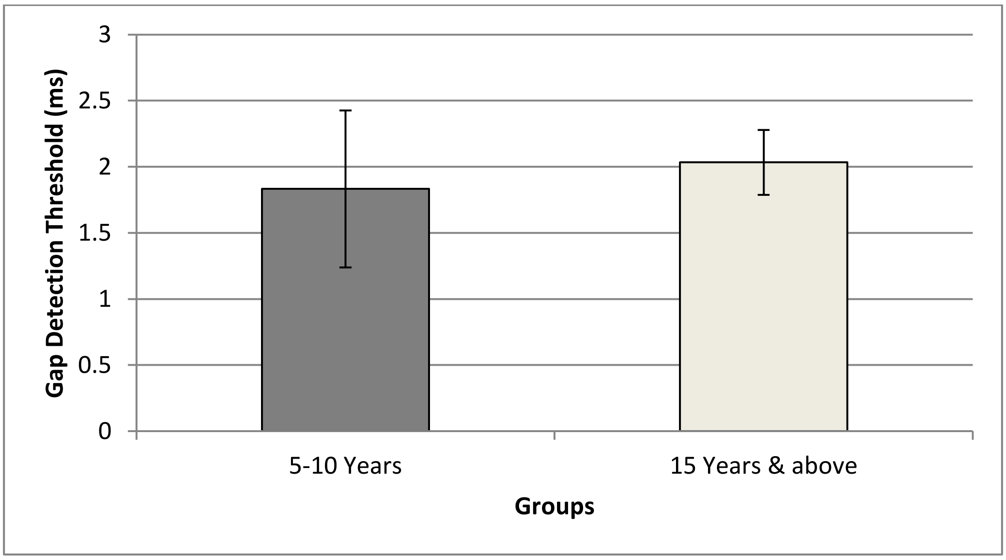

Figure 4.2. Mean and SD of GDT for the two mridangam groups based on their experience

Figure 4.2 shows the mean & SD of GDT for groups based on their experience. Groups are represented in the abscissa and gap detection threshold (ms) are represented in the ordinate.

MANOVA was done to compare GDT between group 1 and group 2. Results revealed statistically no significant difference [F (1, 18) = 0.97, p>0.05] based on experience between mridangam player groups.

Experience wise there was statistically no significant difference between mridangam player groups for TMTF and GDT tests. The reason might be slow rate of promote plasticity in structural/functional changes in the nervous system after 5 years of musical training or practice. Another reason might be the closeness of these groups in terms of their experience. In the absence of the specific literature on TMTF and GDT in musicians it is difficult to explain the result found in the present study.

Speech Perception in Noise

Quick Speech-in-Noise – Kannada (QuickSIN):

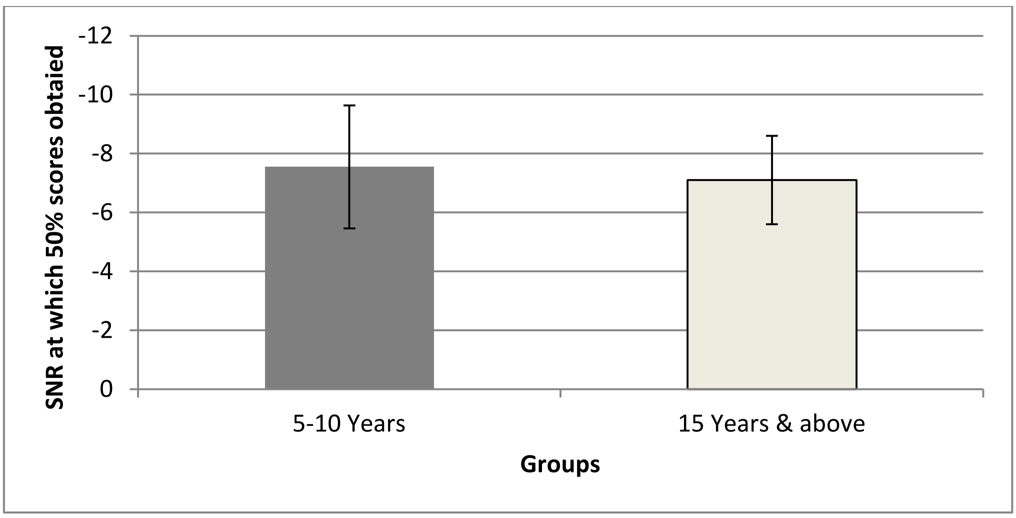

Figure 4.3. Mean and SD of Quick Speech-in-Noise – Kannada for the two mridangam groups based on their experience

Figure 4.3 shows the mean & SD of Quick Speech-in-Noise – Kannada for groups based on their experience. Groups are represented in the abscissa and SNR at which 50% scores obtained are represented in the ordinate.

MANOVA was done to compare QuickSIN between group 1 and group 2. Results revealed statistically no significant difference [$F(1, 18) = 0.30$, $p>0.05$] based on experience between group 1 and group 2. These results are in agreement with the study by Thomas and Rajalakshmi (2011), where it was concluded that speech perception in noise were statistically not significant when the musicians were compared across their experience. But this is in contrast to the previous research done in speech perception abilities in musicians. According to the study done by Parbery-Clark et al. (2009), musical experience resulted in more robust subcortical representation of speech in the presence of background noise.

Since there is statistically no significant difference between 2 mridangam players groups (5-10 years and 15 years above) based on experience in three different tests then it was combined and taken as one musician group and compared with the non-musician group.

Temporal Resolution

Temporal Modulation Transfer Function:

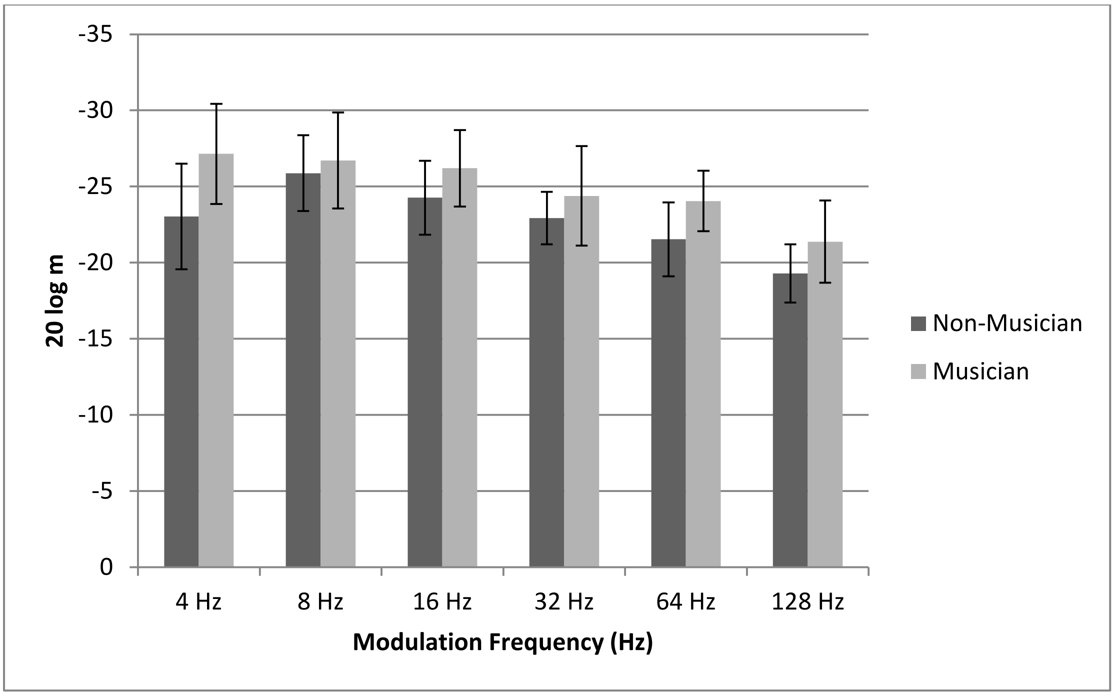

Figure 4.4. Mean and SD of TMTF for non-musician and musician groups at different modulation frequencies

Figure 4.4 shows the mean & SD of the TMTF of all the six modulation frequencies for non-musician and musician groups. Different modulation frequencies (in Hz) are represented in the abscissa and the modulation detection thresholds or modulation depths (as 20 log m) are represented in the ordinate.

Mixed ANOVA was administered to compare TMTF between non-musician and musician. Results revealed statistically significant difference [$F(1, 38) = 13.77$, $p<0.05$] between both groups. There is statistically significant difference across frequencies [$F(5, 190) = 40$, $p<0.05$] and interaction between group and frequency also statistically significant [$F(5, 190) = 2.78$, $p<0.05$].

Bonferroni test was done for the comparison of pair wise frequencies. Results revealed that 4 Hz frequency had statistically significant difference with 64 Hz and 128 Hz ($p<0.05$) frequencies. 8 Hz frequency has statistically significant difference with 32 Hz, 64 Hz and 128 Hz ($p<0.05$) frequencies. 16 Hz frequency has statistically significant difference with 32 Hz, 64 Hz and 128 Hz ($p<0.05$) frequencies. 32 Hz frequency has statistically significant difference with 8 Hz, 16 Hz and 128 Hz ($p<0.05$) frequencies. 64 Hz frequency has statistically significant difference with 4 Hz, 8 Hz, 16 Hz and 128 Hz ($p<0.05$) frequencies. 128 Hz frequency has statistically significant difference with 4 Hz, 8 Hz, 16 Hz, 32 Hz and 64 Hz ($p<0.05$) frequencies.

MANOVA was done for comparison of two groups (non-musician vs musician) within each frequency. Results revealed that groups do not revealed statistically significant difference at 8 Hz [$F (1, 38) = 0.87$, $p>0.05$] and 32 Hz [$F (1, 38) = 3.08$, $p>0.05$] frequencies. In other frequencies like 4 Hz [$F (1, 38) = 14.82$, $p<0.05$], 16 Hz [$F (1, 38) = 6.13$, $p<0.05$], 64 Hz [$F (1, 38) = 12.81$, $p<0.05$] and 128 Hz [$F (1, 38) = 7.99$, $p<0.05$] groups are statistically significant difference.

Repeated measures ANOVA was done for comparison across frequencies within non-musician group. Results revealed that there is a statistically significant [$F (5, 95) = 19.91$, $p<0.05$] difference across frequencies within non-musician group.

Bonferroni test was done for the comparison of pair wise frequencies in non-musicians group. Results revealed that 4 Hz frequency has statistically significant difference with 128 Hz frequency ($p<0.05$). 8 Hz frequency has statistically significant difference with 32 Hz, 64 Hz and 128 Hz frequencies ($p<0.05$). 16 Hz frequency has statistically significant difference with 64 Hz and 128 Hz frequencies ($p<0.05$). 32 Hz frequency has statistically significant difference with 16 Hz and 128

Hz frequencies (p<0.05). 64 Hz frequency has statistically significant difference with 8 Hz, 16 Hz and 128 Hz frequencies (p<0.05). 128 Hz frequency has statistically significant difference with 4 Hz, 8 Hz, 16 Hz, 32 Hz and 64 Hz frequencies (p<0.05).

Repeated measures ANOVA was done for comparison across frequencies within musician group. Results revealed that there is a statistically significant [F (5, 95) = 24.20, p<0.05] difference across frequencies within musician group.

Bonferroni test was done for the comparison of pair wise frequencies in musicians group. Results revealed that 4 Hz frequency has statistically significant difference with 64 Hz and 128 Hz frequencies (p<0.05). 8 Hz frequency has statistically significant difference with 64 Hz and 128 Hz frequencies (p<0.05). 16 Hz frequency has statistically significant difference with 64 Hz and 128 Hz frequencies (p<0.05). 32 Hz frequency has statistically significant difference with 128 Hz frequency (p<0.05). 64 Hz frequency has statistically significant difference with 4 Hz, 8 Hz and 16 Hz frequencies (p<0.05). 128 Hz frequency has statistically significant difference with 4 Hz, 8 Hz, 16 Hz, 32 Hz and 64 Hz frequencies (p<0.05).

Gap Detection Threshold (GDT):

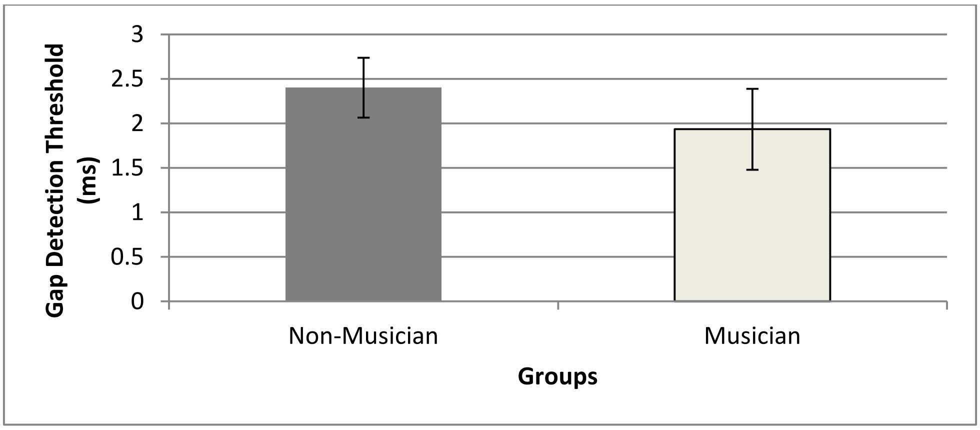

Figure 4.5. Mean and standard deviation (SD) of GDT for the two groups (Non-Musician vs musician)

Figure 4.5 shows the mean & SD of GDT for non-musician and musician groups. Groups are represented in the abscissa and gap detection threshold (ms) are represented in the ordinate.

MANOVA was done for comparison of two groups (Non-Musician vs musician). Results revealed statistically significant difference between groups [F (1, 38) = 13.68, $p<0.05$].

The results of TMTF and GDT tests across the two groups (Non-Musician vs musician) revealed statistically significant difference. These results is in agreement with Monteiro et al. (2010), who reported that musicians had better temporal resolution abilities compared to non-musicians. Rammsayer and Altenmuller (2006) concluded that superior temporal acuity for musicians compared to non-musicians. Rajalakshmi and Bhushan (2012) concluded that the temporal resolution abilities were better in children with musical training than compared to children without musical training.

Speech Perception in Noise

Quick Speech-in-Noise – Kannada (QuickSIN):

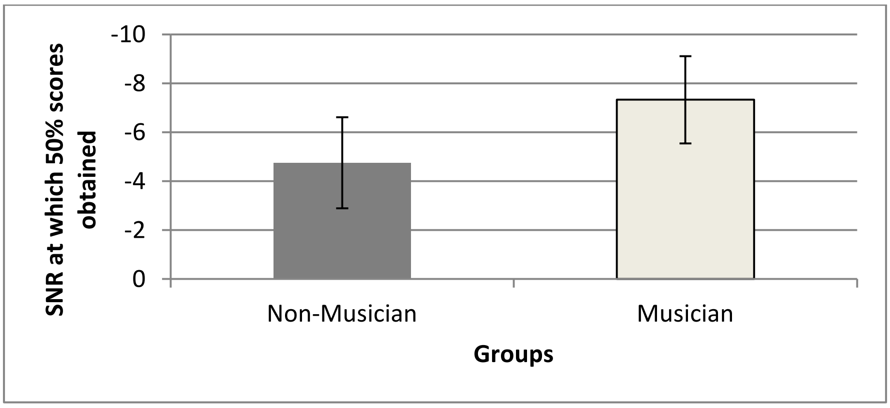

Figure 4.6. Mean and SD of QuickSIN for the two groups (Non-Musician vs musician)

Figure 4.6 shows the mean & SD of Quick Speech-in-Noise – Kannada (QuickSIN) for two groups (Non-Musician vs musician). Groups are represented in the abscissa and SNR at which 50% scores obtained are represented in the ordinate.

MANOVA was done for comparison between non-musician and musician groups. Results revealed statistically significant difference [$F(1, 38) = 19.93$, $p<0.05$] between groups.

The results of QuickSIN test across the two groups (Non-Musician vs musician) revealed statistically significant difference. These results are in agreement with Parbey-Clark et al. (2009), who reported that a distinct speech in noise advantages for musicians, as measured by standardized test of hearing in noise. Rajalakshmi and Bhusan (2012) also reported that the ability to perceive speech in the presence of background noise was better in children with musical training than compared to children without musical training. Janet and Yathiraj (2003) reported that that the speech-in-noise scores of musically trained children are better and they gave reason for that the enhancement in speech-in-noise scores seen in musically trained children could be due to the training to listen to the melody played while a constant rhythm is played in the background. However, the present result is not in agreement with Thomas & Rajalakshmi (2011), where in speech perception in background noise was not statistically significant between musicians and non musicians. This difference may be attributed to the noise used for the test. The previous study used speech noise whereas; the present study used multi-talker babble. Also the subject participated in the two studies are different, the previous study being vocalic and the present study being mridangam players.

CHAPTER V

SUMMARY AND CONCLUSIONS

Many studies have reported that musicians have better auditory perceptual skills when compared to non-musicians. There are many studies in literature which have documented that musical training improves basic auditory perceptual skills resulting in enhanced behavioral (Jeon & Fricke 1997; Koelsch et al., 1999; Oxenham et al., 2003; Tervaniemi et al., 2005; Micheyl et al., 2006; Rammsayer & Altenmuller 2006) and neurophysiological responses (Brattico et al., 2001; Pantev et al., 2001; Schneider et al., 2002; Shahin et al., 2003, 2007; Tervaniemi et al., 2005; Kuriki et al., 2006; Kraus et al., 2009). Musicians life long experience of detecting melodies from background harmonies can be considered as a process analogous to speech perception in noise. Studies report that musicians had a more robust sub- cortical representation of the acoustic stimulus in the presence of noise (Kraus et al., 2009). Musical practice not only enhances the processing of music related sounds but also influences processing of other domains such as language (Marques et al., 2007; Moreno et al., 2009; Parbery-Clark et al., 2009a; Schon et al., 2004, 2008). Because of their musical training, musicians have learned to pay more attention to the details of the acoustic stimulus than non-musicians. However, there is a dearth of literature regarding whether those advantages are exhibited by percussion instrument players like mridangam players.

The present study aimed to observe the temporal resolution abilities of mridangam players. Also, to find the speech perception abilities in the presence of background noise for the same group. An informal questionnaire was administered to all participants, in order to get the information regarding their experience in the musical field. The musicians were classified into two groups based on their experience and/or practice. Each group consisted of 10 subjects. Control group consisted of age matched 20 normal hearing non- musicians. Temporal resolution abilities were found out using Temporal Modulation Transfer Function (TMTF) and Gap Detection Threshold (GDT) test. Quick Speech Perception in Noise – Kannada (QuickSIN) was administered to check speech perception in the presence of noise. All these tests were administered at 40 dB SL or at most comfortable level, for binaurally.

The results from the present study showed that the temporal resolution abilities and the ability to perceive speech in the presence of noise were better in musicians than compared to non-musicians. Musical training as a factor has contributed to better performance in musicians. But the results of the temporal resolution abilities and the ability to perceive speech in the presence of background noise were statistically not significant when the musicians were compared across their experience.

Implications of the Study

- To add information to the literature.
- Music training can be used as a potential remediation strategy for children requiring language training and auditory processing disorders.
- Can be implemented in Hearing Aid technology for musicians with hearing loss to improve their speech perception.

Future Directions for Research

- The present study can be replicated using more number of participants to find the difference across the experience.

- Same skills can be compared across vocal musicians and instrumental musicians.
- Can be compared between Hindustani and Carnatic musicians.
- Musicians and dancers can be compared to find whether there are differences in the temporal resolution abilities and ability to perceive speech in the presence of noise.

REFERENCES

Alain, C., & Brenstein, L. J. (2008). From sound to meaning: The role of attention during auditory scene analysis. *Current Opinions of Otolaryngologica: Head and Neck Surgery, 16*, 485-489.

American National Standards Institute (1991). *Maximum Ambient Noise Levels for Audiometric Test Rooms*. (ANSI S3. 1-1991). New York: American National Standards Institute.

Assmann, P. F., & Summerfield, Q. (1990). Modeling the perception of concurrent vowels: Vowels with different fundamental frequencies. *Journal of Acoustical Society of America, 88*, 680-697.

Avinash, M. C., Methi, R. R., & Kumar, A. U. (2009). Development of sentence material for Quick Speech in Noise test (Quick SIN) in Kannada. *Journal of Indian Speech and Hearing Association, 23(1),* 59-65.

Beavois, M. W., & Meddis, R. (1997). Time decay of auditory stream biasing. *Perception and Psychophysics, 59,* 81-86.

Besson, M., Schon, D., Moreno, S., Santos, A., & Magne, C. (2007). Influence of musical expertise and musical training on pitch processing in music and language. *Restorative Neurology and Neuroscience, 25*, 399-410.

Bialystok, M. W., & DePape, A. M. (2009). Musical expertise, bilingualism, and executive functioning. Journal of Experimental Psychology: *Human Perception and Performance, 35*, 565-574.

Boersma, P., & Weenick, D. (2005). *Praat doing phonetics by computer* (version 4.6.09) from www.praat.org

Bradlow, A. R., Kraus, N., & Hayes, E. (2003). Speaking clearly for children with learning disabilities: sentence perception in noise. *Journal of Speech Language and Hearing Research, 46,* 80-97.

Brandler, S., & Rammsayer, T. H. (2003). Differences in mental abilities between musicians and non-musicians. *Psychology of Music, 31 (2),* 123-138.

Brandt, J., & Rosen, J. J. (1980). Auditory phonemic perception in dyslexia: Categorical identification and discrimination of stop consonants. *Brain and language, 9*, 324-337.

Brattico, E., Naatanen, R., & Tervaniemi, M. (2001). Context effects on pitch perception in musicians and nonmusicians: Evidence for event related potentials. *Music Perception, 19*, 199-222.

Bregman, A. S. (1990). *Auditory Scene Analysis: The Perceptual Organization of Sound*. Cambridge, MA: MIT Press.

Brokx, J. P. L., & Nooteboom, S. G. (1982). Intonation and the perceptual separation of simultaneous voice. *Journal of Phonetics, 10*, 23-36.

Carhart, R., & Jerger, J. F. (1959). Preferred method for clinical determination of pure tone thresholds, *Journal of Speech and Hearing Disorders, 36*, 476-483.

Chan, A. S., Ho, Y. C., & Cheung, M. C. (1998). Music training improves verbal memory. *Nature, 396*, 128.

Chandrasekaran, B., Krishnan, A., & Gandour, J. T. (2009). Relative influence of musical and linguistic experience on early cortical processing of pitch contours. *Brain and Language, 108*, 1-9.

Elbert, T., Pantev, C., Wienbruch, C., Rockstroh, B., & Taub, E. (1995). Increased cortical representation of the fingers of the left hand in string players. *Science, 270 (5)*, 305-307.

Foregeard, M., Schlaug, G., Norton, A., Rosam, C., Iyengar, U., & Winner, E. (2008). The relation between music and phonological processing in normal-reading children and children with dyslexia. *Music Perception, 25*, 383-390.

Foregeard, M., Winner, E., Norton, A., & Schlaug, G. (2008). Practicing a musical instrument in childhood is associated with enhanced verbal ability and nonverbal reasoning. *PLoS One, 3*, 35-66.

Fujioka, T., Trainor, L., & Ross, B. (2008). Simultaneous pitches are encoded separately in auditory cortex: An MMN study. *Neuroreport, 19*, 361-368.

Fujioka, T., Trainor, L. J., & Ross, B. (2005). Automatic encoding of polyphonic melodies in musicians and nonmusicians. *Journal of Cognitive Neuroscience, 17*, 1578-1592.

Fujioka, T., Trainor, L., Ross, B., Kakigi, R., & Pantev, C. (2004). Musical training enhances automatic encoding of melodic contour and interval structure. *Journal of Cognitive neuroscience, 16(6)*, 1010-1021.

Gaser, C., & Schlaug, G. (2003). Brain structures differ between musicians and non-musicians. *Journal of Neurosciences, 23 (27)*, 9240-9245.

Gordon-Salant, S., & Fitzgibbons, P. J. (1995). Recognition of multiply degraded speech by young and elderly listeners. *Journal of Speech Language and Hearing Research, 38*, 1150-1156.

Ho, Y.C., Cheung, H. C., & Chan, A. S. (2003). Music training improves verbal but not visual memory: Cross sectional and longitudinal explorations in children. *Neuropsychology, 17*, 439-450.

Hoormann, J., Falkenstein, M., Hohnsbein, J., Blanke, L. (1992). The human frequency-following response (FFR): normal variability and relation to the click-evoked brainstem response. *Hearing Research 59*, 179–88.

Hebb, D.O. (1949). *The Organization of Behavior*. New York: Wiley & Sons.

Ishll, C., Arashiro, A. M., & Pereira, L. D. (2006). Ordering and temporal resolution professional singers and amateurs tuned and un-tuned. *Pro-Fono, 18(3)*, 285-292.

Jackobsen, L. S., Cuddy, L. L., & Kilgour, A. R. (2003). Time tagging: A key to musicians' superior memory. *Music Perception, 20*, 307-313.

Jakobson, L. S., Lewycky, S.T., Kilgour, A. R., & Stoesz, B. M. (2008). Memory for verbal and visual material in highly trained musicians. *Music Perception, 26*, 41-55.

Janet, D., & Yathiraj, A. (2003). Effect of Music Training on Auditory Perceptual Skills. Unpublished Master's Dissertation, University of Mysore.

Jeon, J. Y., & Fricke, F. R. (1997). Duration of perceived and performed sounds. *Psychology of Music, 25*, 70–83.

Jones, M. R., & Yee, W. (1997). Sensitivity to time change: The role of context and skill. *Journal of Experimental Psychology: Human Perception and Performance, 23*, 693-709.

Koelsch, S., & Mulder, J., (2002). Electric brain responses to inappropriate harmonies during listening to expressive music. *Clinical Neurophysiology*, *113*, 862-869.

Koelsch, S., Schroger, E., & Tervaniemi, M. (1999). Superior attentive and pre-attentive auditory processing in musicians. *Neuroreport, 10*, 1309– 1313.

Koelsch, S., Schulze, K., & Sammler, D. (2008). Functional architecture of verbal and tonal working memory: An fMRI study. *Human Brain Mapping, 30*, 859-873.

Koffka, K. (1935). Principles of Gestalt Psychology. New York: Harcourt, Brace and World.

Kraus, N., & Banai, K. (2007). Auditory-processing malleability: Focus on language and music. Current Directory of Psychological Sciences, 16, 105-110.

Kraus, N., Skoe, E., Parbery-Clark, A., & Ashley, R. (2009). Experience induced malleability in neural encoding of pitch, timbre and timing: implications for language and music. *Annals of New York Academy of Sciences 1169*, 543-557.

Krishnan, A., Xu, Y.S., Gandour, J.T. & Cariani, P. (2005). Encoding of pitch inthe human brainstem is sensitive to language experience. *Cognitive. Brain Research. 25*, 161–168

Kuriki, S., Kanda, S., & Hirata, Y. (2006). Effects of musical experience on different components of MEG responses elicited by sequential piano-tones and chords. *Journal of Neuroscience*, *26*, 4046–4053.

Lee, K. M., Skoe, E., Kraus, N., & Ashley, R. (2009). Selective subcortical enhancement of musical intervals in musicians. *Journal of Neurosciences, 29,* 5832-5840.

Levit, H. (1971). Transformed Up-Down methods in psychoacoustics, *Journal of Acoustical Society of America, 49,* 467-477.

Magne, C., Schon, D., & Besson, M. (2006). Musician children detect pitch violations in music and language better than non-musician children: Behavioural and electro-physiological approaches. *Journal of Cognitive Neurosciences, 18,* 199-211.

Marques, C., Moreno, S., & Casstro, S. L. (2007). Musicians detect pitch violation in a foreign language better than nonmusicians: Behavioural and electrophysiological evidence. *Journal of Cognition and Neuroscience, 19,* 1453–1463.

Micheyl, C., Delhommeau, K., Perrot, X., & Oxenham, A. J. (2006). Influence of musical and psycho acoustical training on pitch discrimination. *Hearing Research, 219,* 36–47.

Monteiro, R. A., Nascimento, F. M., Soares, C. D., & Ferreira, M. D. (2010). Temporal resolution abilities in Musicians and no musicians. *International Archives of Otolaryngology, 14(3),* 302-308.

Moreno, S., Marques, C., Santos, A., Santos, M., Castro, S.L., & Besson, M. (2009). Musical training influences linguistic abilities in 8-year old children: more evidence for brain plasticity. *Cerebral Cortex 19*, 712-723.

Musacchia, G., Sams, M., Skoe, E., & Kraus, N. (2007). Musicians have enhanced subcortical auditory and audiovisual processing of speech and music. *Proceedings of the National Academy of Sciences of United States of America, 104,* 15894-15898.

Musacchia, G., Strait, D., & Kraus, N. (2008). Relationships between behavior, brainstem and cortical encoding of seen and heard speech in musicians and non-musicians. *Hearing Research, 241,* 34–42.

Musiek, F. E., Shinn, J. B., & Jirsa, R. Bamiou, D. E., Baran, J. A., & Zaida, E. (2005). The GIN (Gaps-In-Noise) test performance in subjects with confirmed central auditory nervous system involvement. *Ear and Hearing*, 26, 608-617.

Nair, D., Large, W. E., Steinberg, F., & Kelso, J. A. S. (2002). Expressive timing and perception of emotion in music: an fMRI study. *Proceeding of the 7th International Conference on Music Perception and Cognition, 627,* 627-630.

Ohinshi, T., Matsuda, H., Asada, T., Aruga, M., Hirakata, M., & Nishikawa, M., Katoh, A., & Imabayashi, E. (2001). Functional Anatomy of Musical Perception in Musicians. *Cerebral Cortex, 11(8),* 75-760.

Oxenham, A. J., Fligor, B. J., Mason, C. R., & Kidd, G. (2003). Informational masking and musical training. *Journal of Acoustical Society of America, 114*, 1543–1549.

Pantev, C., Oostenveld, R., Engelien, A., Ross, B., Roberts, L.E., & Hoke, M. (1998). Increased auditory cortical representation in musicians. *Nature, 392,* 811–814.

Pantev, C., Roberts, L. E., Schulz, M., Engelien, A., Almut., Ross., & Bernhard. (2001). Timbre-specific enhancement of auditory cortical representations in musicians. *Neuroreport, 12*, 169–174.

Parbery-Clark, A., Skoe, E., & Kraus, N. (2009). Musical experience limits the degradative effects of background noise on the neural processing of sound. *Journal of Neuroscience, 29*, 14100-14107.

Patel, A. D. (2003). Language, music, syntax and the brain. *Natural Neuroscience, 6*, 674-681.

Patel, A. D. (2007). *Music, Language and the Brain*. Oxford: Oxford University Press.

Rajalakshmi, K., & Bhushan, B. (2012). Comparison of temporal resolution abilities and speech perception in noise in children born in families with musical background and children born in families without musical background. Unpublished department project in department of Audiology, AIISH, Mysore.

Rajashekar, B & Vyasamurthy, M. N. (1976). *Development and standardization of a picture SRT test for adults and children in Kannada*. Unpublished Master's Dissertation, University of Mysore.

Rammsayer, T., & Altenmuller, E. (2006). Temporal information processing in musicians and non-musicians. *Music Perception, 24*, 37-48.

Samelli, A. J., & Schochat, E. (2008). The gaps-in-noise test: Gap detection thresholds in normal-hearing young adults. *International Journal of Audiology, 47*, 238-245.

Scheffers, M., (1983). *Sifting Vowels: Auditory Pitch Analysis and Sound Segregation*. Unpublished Doctoral dissertation. Groningen. The Netherlands: Groningen University.

Schlaug, G. (2001). The brain of musicians: a model for functional and structural adaptation. *Annals of New York Academy of Sciences, 930,* 281-299.

Schlaug, G., Norton, A., Overy, K., & Winner, E. (2005). Effects of music training on the child's brain and cognitive development. *Annals of New York Academy of Sciences, 930*, 281-299.

Schneider, P., Scherg, M., & Dosch, H. G. (2002). Morphology of Heschl's gyrus reflects enhanced activation in the auditory cortex of musicians. *Natural Neuroscience, 5*, 688-694.

Schon, D., Magne, C., & Besson, M. (2004). The music of speech: Music training facilitates pitch processing in both music and language. *Psychophysiology, 41*, 341–349.

Shahin, A. J., Roberts, L. E., & Pantev, C. (2007). Enhanced anterior-temporal processing for complex tones in musicians. *Clinical Neurophysiology, 118,* 209–220.

Shahin, A., Bosnyak, D. J., Trainor, L. J., & Robertsm, L. E. (2003). Enhancement of neuro-plastic P2 and N1c auditory evoked potentials in musicians. *Journal of Neuroscience, 23,* 5545–5552.

Strait, D., Kraus, N., Parbery-Clark, A., & Ashley, R. (2010). Musical experience shapes top-down auditory mechanisms: Evidence from masking and auditory attention performance. *Hearing Research, 261*, 22-29.

Strait, D., Kraus, N., Skoe, E., & Ashley, R. (2009). Musical experience and neural efficiency: Effects of training on subcortical processing of vocal expressions of emotion. *European Journal of Neuroscience, 29*, 661-668.

Tervaniemi, M., Just, V., Koelsch, S., Widmann, A., & Schorger, E. (2005). Pitch discrimination accuracy in musicians vs. non-musicians: an event-related potential and behavioural study. *Experimental Brain Research, 161,* 1- 10.

Thomas, A. O., & Rajalakshmi, K. (2011). Effect of musical training on temporal resolution abilities and speech perception in noise. Published Master's Dissertation, University of Mysore.

Thompson, W. F., Schellenberg, E. G., & Husain, G. (2004). Decoding speech prosody: Do music lessons help? *Emotion, 4*, 46-64.

Treisman, A. M. (1964). Verbal cues, language and meaning in selective attention. *American Journal of Psychology*, *77*, 206-219.

Tremblay, K., Kraus, N., McGee, T., Ponton, C., & Otis, B. (2001). Central auditory plasticity: changes in the N1–P2 complex after speech-sound training. *Ear Hear*. *22*, 79–90.

Wong, P. C., & Perrachione, T. K. (2007). Learning pitch patterns in lexical identification by native English speaking adults. *Applied Psycholinguistics, 28*, 565-585.

Wong, P. C., Skoe, E., Russo, N. M., Dees, T., & Kraus, N. (2007). Musical experience shapes human brainstem encoding of linguistic pitch patterns. *Nature Neuroscience*, *10*, 420-422.

Yathiraj, A., & Vijayalakshmi, C. S. (2005). *Phonemically Balanced word list in Kannada.* Developed in Department of Audiology, AIISH, Mysore.

Yee, W., Holleran, S., & Jones, M. R. (1994). Sensitivity to event timing in regular and irregular sequences: Influences of musical skill. *Perception & Psychopsysics, 56*, 461-471.

Zendel, B. R., & Alain, C. (2009). Concurrent sound segregation is enhanced in musicians. *Journal of Cognitive Neuroscience, 21,* 1488-1498.

Ziegler, J. C., Pech-Georgel, C., George, F., Alario, F. X., & Lorenzi, C. (2005). Deficits in speech perception predict language learning impairment. *Proceedings of National Academic Science USA, 102*, 14110-14115.

Zhang, Y., & Suga, N. (1997). Corticofugal amplification of subcortical responses to single tone stimuli in the mustached bat. *Journal of Neurophysiology, 78,* 3489-3492.