EFFECT OF CARNATIC VOCAL MUSICAL TRAINING ON TEMPORAL RESOLUTION, FREQUENCY DISCRIMINATION AND SPEECH PERCEPTION IN NOISE IN CHILDREN

Jumana Mithlaj. A. K

17AUD019

This Dissertation is submitted as a part of fulfillment

For the Degree of Masters of Science in Audiology

University of Mysore, Mysore

All India Institute of Speech and Hearing,

Manasagangothri, Mysore – 570 006

May 2019

CERTIFICATE

This is to certify that this dissertation entitled '**Effect of Carnatic vocal musical training on temporal resolution, frequency discrimination and speech perception in noise in children**' is the bonafide work submitted in part fulfilment for the Degree of Master of Science (Audiology) of the student with the Registration No:**17AUD019.** 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 M. Pushpavathi

Director

Mysuru All India Institute of Speech and Hearing,

May 2019 Manasagangothri, Mysore – 570 006

CERTIFICATE

This is to certify that this dissertation entitled '**Effect of Carnatic vocal musical training on temporal resolution, frequency discrimination and speech perception in noise in children**' has been prepared under my supervision and guidance. It is also certified that this has not been submitted earlier to any other University for the award of any other Diploma or Degree.

Dr Ajith Kumar U

Guide

Professor of Audiology,

Department of Audiology,

All India Institute of Speech and Hearing,

Manasagangothri, Mysore – 570 006

Mysuru

May 2019

DECLARATION

This is to certify that this Master's dissertation entitled '**Effect of Carnatic vocal musical training on temporal resolution, frequency discrimination and speech perception in noise in children**' is the result of my own study under the guidance of Dr. Ajith Kumar U, Professor of 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.

Mysuru **Register No: 17AUD019**

May 2019

Acknowledgement

*Dedicated to my superwoman (**Umma**) and **Uppa**.*

*Dearest **Umma** and **Uppa**, thank you for everything. Thank you for believing in me at my every step taken, for giving me the strength that i required to pursue my dreams. I can't thank you both enough for everything you have done for me.*

*My heartfelt gratitude to my guide, **Dr Ajith Kumar u**. Sir, you are a true inspiration. I was always fascinated with your immense knowledge, dedication and patience. Thank you for keeping calm with me and being the coolest and bestest guide ever.*

*I would like to utilise this opportunity to thank **Anoop sir**, for being a wonderful co-guide and helping me every time I needed it. Thank you so much for your extremely generous support.*

*I would like to thank our beloved Director, **Dr.M Pushpavathi** for giving this opportunity to carry out the study.*

*I would like to thank **Srikar sir** and **Shreyank** sir for your kind support and help.*

*I thank **Ravi sir** for helping me with the softwares.*

*I would like to thank all my **teachers** and faculties in AIISH for enlightening me with knowledge.*

Thank you ***Sreeraj sir, Prasanth sir, Sandeep sir, Asha mam, Ganapathy sir, Sharath sir, Antony sir, Animesh sir****,* ***Sujeet sir*** *and* ***Vikas sir*** *for all the lessons in audiology as well in life.*

My sincere thanks to ***Jayan sir*** *and all my* ***participants*** *for their co-operation to complete this study.*

Cchanda *and* ***Anu****, my dissertation sisters, thank you for having the same IQ as me. Cheers to all our hide and seek plays, hiding in the canteen, running away and towards the guide. Thank you for giving me the best dissertation experiences*

Hibu*, I feel so blessed and grateful to be your sister. Thank you for being the most beautiful person, inside and out. You always have solutions for all my problems. You are one call away to do anything for me. Thank you again for being born.*

Thank you ***Rishu****, for being the best brother and my unpaid driver.*

Monu, *I am the luckiest to have a goddaughter like you. You are one thing that keeps me going. Thank you for showing me beautiful things in my life.*

My dearest friends, ***Reshlu*** *(most modern),* ***Nayana*** *(Kari),* ***Deka*** *(Australian tomato),* ***Barja*** *(Ku***),* ***Ammini****, thank you for the laughs, for the cries, and for everything in between.*

Driver*, You gave me hope when I thought the hope was gone. Thank you for always understanding and for giving me your time. Thank you for giving me the best opinions whenever I felt so indecisive. Just so you know, you're one of the few people I truly look up to.*

*I would like to thank my classmates (**Lunatics & 40Hz**), **juniors** and **seniors** for making the six short years we have been friends feel like forever and for giving me enough memories to last a lifetime.*

*My ex-roomie, **Sonia** (azhka payal), you are truly the beauty of AIISH. One pure soul and the most genuine person i met. Thank you for being a good friend.*

*Thank you my babygals, **Aslin** (Suresh), **Gansa** (Dimpley), **Krishna** (Appi), **Persu**, **Nuha** (Molu) and **Neha** kutty for keeping me with the company and for making my final year hostel life memorable and happy. I will miss you all.*

***Neha**, my panchasara, thank you for being the best of all (how mlecham). I love you and will miss you.*

*Thank you **Divya** and **Durga** for helping me with the dissertation in the last minute.*

*Special mention to my posting mates **Yash** (dance partner), **Sharanya**, **Mohini**, **Saranya**, **Satish** and also to **Kavya**, **DSK**, **Jagrathi** (my twin), **Abhi**, **Ashique** and **Johny**.*

Lastly, thank you to everybody who has been a part of my six years of college life. Words won't be enough to thank you all for the change I experienced in me.

ABSTRACT

The present study aimed at investigating the effect of Carnatic vocal musical training on psychophysical abilities and speech perception in noise. A total of 40 children in the age range of 10 to 11 years participated in the study. Participants were divided into two groups where group 1 consisted of normal hearing children who are under musical training for at least 3 years and group 2 consisted of normal hearing children who did not have any formal musical training. Gap detection threshold, temporal modulation transfer function and difference limen frequency were measured using mlp toolbox implemented in MATLAB software. SPIN scores were measured using Malayalam sentences in the presence of multi-talker babble at 0dB SNR. Dichotic CV responses were measured with respect to single correct scores and double correct scores. The study concludes that Carnatic vocal musical training enhances pitch discrimination ability in children.

Keywords: *musical training, temporal resolution, frequency discrimination, speech perception in noise.*

TABLE OF CONTENTS

List of tables

List of figures

Chapter 1

Introduction

Carnatic music is one of the major genres of Indian classical music system which is performed by a single musician or in a group. Most often, a Carnatic music performance is accompanied by a shruthi box to match the shruthi, which refers to the foundational pitch or frequency of the performer's choice. Through Carnatic musical training, individual expertise in discriminating shruthi which refers to the pitch, also melody and rhythm. However, such improvements could be found after intensive and prolonged training in music (Moreno & Besson, 2006; Schlaug, Forgeard, Zhu, Norton, & Winner, 2009). It has been shown that musical training can bring about both behavioural as well as structural and functional changes in auditory system (Hyde et al., 2009a; Koelsch, Fritz, Schulze, Alsop, & Schlaug, 2005; Kraus & Chandrasekaran, 2010; Magne, Schön, & Besson, 2006; Moreno, Marques, Santos, Castro, & Besson, 2009; Schlaug, Forgeard, Zhu, Norton, & Winner, 2009; Schlaug, Norton, Overy, & Winner, 2005)

Earlier studies investigating auditory behaviours in trained musicians have reported enhanced behavioural and neurophysiological responses (Chandrasekaran, Krishnan, & Gandour, 2009; Fujioka, Ross, Kakigi, Pantev, & Trainor, 2006a; Magne, Schon & Besson, 2006; Micheyl, Delhommeau, Perrot, & Oxenham, 2006; Moreno & Besson, 2006; Shahin, Bosnyak, Trainor, & Roberts, 2003b; Shahin, Roberts, Pantev, Aziz, & Picton, 2007). The musical training-induced neural plasticity is proportional to years of training and persists into late adulthood (Kraus & Skoe, 2012). In this line, children who began musical training at an early age showed enhanced cortical potentials compared to other children (Pantev, Oostenveld, Rose, Roberts, & Hoke, 1998). Trainor et al. (2003) correlated the age of onset of musical training and the amplitude of P3 and reported an enhanced P3 potential in children who started the training as young as four years of age. Similar findings were reported by Pantev et al. (1998) on examining the effect of age of onset of musical training on the amplitude of N1b response. In an MRI study, Schlaug, Schulze, Koelsch, Fritz, and Alsop (2005) found that children who were under musical training for four years had significantly more grey matter volume in various areas of the brain including the sensorimotor cortex than other children.

Musical training is also known to enhance the perception and neural encoding of speech in noise (Strait, Parbery-Clark, Hittner, & Kraus, 2012). This could be attributed to the strengthening of auditory specific cognitive abilities like auditory working memory and auditory attention and training-induced neuroplasticity in children (Fujioka et al., 2006a; Hyde et al., 2009b; Schlaug et al., 2009). Psychoacoustical studies on trained musicians have reported improved ability to discriminate small pitch variations (Estis, Dean-Claytor, Moore, & Rowell, 2011). Besson, Magne, and Schon (2006) demonstrated that performance in pitch detection task was superior in children with intensive long-term musical training. However, Moreno and Besson (2006) reported no effect of short-term musical training (8 weeks) on performance in pitch discrimination task. Hence, it can be concluded that long-term musical training enhances pitch perception, which might also influence speech perception.

Indian Carnatic music, in comparison with Western music, has a completely different basis of training where Carnatic music focuses on raaga, taal, microtones or shruthi. Studies have reported positive effects of Carnatic musical training on auditory skills including auditory memory and speech in noise perception over non-musicians (Devi & Swathi, 2016; Jain, Sahana, & Vinutha, 2016; Kumar, Sanju, & Nikhil, 2016; Mishra, Panda, & Herbert, 2014; Mishra, Panda, & Raj, 2015; Sanju; & Kumar, 2016; Sanju & Kumar, 2016). Mishra, Raj, and Panda (2015) studied the influence of Carnatic musical training on the sensitivity to temporal fine structure and suggested that musicians had superior temporal fine structure encoding than non-musicians. They observed that more experienced musicians performed more accurately on the TFS tests compared to less experienced musicians.Similar findings were reported in another study (Jain, Sahana, & Vinutha, 2016) where they revealed a better perception of fine structure cues in Carnatic music trained children in comparison to non-trained children.

1.1 Need for the study

Previous literature in this area shows that musical training leads to enhanced cortical responses, better performance in pitch discrimination and perception of speech in noise. Although enhanced auditory skills in long-term western musical training have been reported, contradictory findings are also documented (Moreno & Besson, 2006). Also, the effect of Carnatic musical training on auditory skills like temporal processing, frequency discrimination and perception of speech in noise in children is less studied. Thus, there is a need to execute a study on children who have been training for Carnatic vocal music to see if the training helps in the early development of auditory processes. The findings of such a study would help in better understanding of changes in auditory behaviour and underlying neuro-plastic changes. Hence, the present study was taken up.

1.2 Aim of the study

The study aims to evaluate the influence of Carnatic vocal music training on the early development of the auditory processes.

1.3 Objectives of the study

1. To compare the Speech perception in noise (SPIN) in musically trained and non-trained children using Malayalam sentences.
2. To compare the temporal processing using gap detection thresholds and temporal modulation detection thresholds in musically trained and non-trained children.
3. To compare dichotic CV test results in musically trained and non-trained children.
4. To compare the frequency difference limen in musically trained and non-trained children.

Chapter 2

Review of Literature

Many studies done in the past years have revealed the advantages of musical training when compared to non-trained individuals. Studies have reported that musical training can not only enhance the music perception but also it improves various other aspects like linguistic skills (Lorenzo, Herrera, Hernández-Candelas, & Badea, 2014; Moreno, Marques, Santos, Castro, & Besson, 2009), speech perception in noise (Anderson & Kraus, 2011; Kraus et al., 2014; Whitton, Hancock, Shannon, & Polley, 2017), attention & memory (Besson, Chobert, & Marie, 2011a), cognitive skills (Miendlarzewska & Trost, 2014) and pitch processing (Besson, Schön, Moreno, Santos, & Magne, 2007; Kishon-Rabin, Amir, Vexler, & Zaltz, 2001; Magne et al., 2006; Micheyl et al., 2006). Over the years, studies have reported an enhancement in auditory skills through various behavioural and cortical potentials (Chandrasekaran, Krishnan, & Gnadour, 2009; Fujioka et al., 2006b; Moreno & Besson, 2006; Strait, Kraus, Skoe, & Ashley, 2009). There are studies reporting an increased cortical maturation (Hudziak et al., 2014) and neuroplastic changes due to musical training (Herholz & Zatorre, 2012; Shahin et al., 2003a)

2.1 Changes in structural and functional aspects of the nervous system

Differences between musicians and non-musicians in neural structure and function have been demonstrated by measuring cortical evoked potentials and Magnetic Resonance Imaging techniques. Hyde et al. (2009) reported an improvement in plasticity in brain regions that control primary functions important for playing a musical instrument, and also the regions that might be responsible for the kind of multimodal sensorimotor integration likely to underlie instrumental learning. These results provide new evidence for training-induced structural brain plasticity in early childhood and that the long-term training programs can facilitate neuroplasticity in children. Schlaug et al. (2009) showed an effect of training practice intensity on subregions of Corpus Callosum mainly the prefrontal cortex, premotor, and supplementary motor areas through diffused tensor image studies. This effect of instrumental music training on structural development of the CC might be due to growth of myelination (axons with thicker myelin sheets), axon size, the increased formation of axon collaterals, or number of transcallosal fibers that could result from interference of bimanual activities in the pruning of interhemispheric fibers during development (Schlaug et al., 2009).

In another fMRI study, musicians elicited activations of IFLC, vlPMC, anterior and posterior temporal lobe structures, OFLC, and anterior insula for unexpected chords (contrasted to expected chords) of musical instruments. Activations of each of these structures were observed in both hemispheres, although activations of IFLC, vlPMC, and temporal lobe structures had a right- hemispheric weighting (Koelsch et al., 2005). In the right hemisphere, the activation pattern of children was very similar to that of adults, except that no SMG activation was observed. In the left hemisphere, only the OFLC and the anterior portion of the STG were significantly activated in children. The early practice of music can have an influence on brain plasticity (Herholz & Zatorre, 2012). Studies reported an increase in the amplitude of the N300 component after music training (Moreno et al., 2009). Fujioka et al. (2006) reported an enhanced negative magnetic evoked response (N250m) to violin tones in musically trained children compared to non-trained children. Musical training is also associated with cortical thickness development as reported in a study done by Hudziak et al. (2014). The increased cortical maturation in regions like premotor and primary motor cortices as an effect of musical training could be due to their role in the preparation, sensory guidance, planning and coordination of movement which are also listed as the key skills in musical practice (Hudziak et al., 2014).

Studies reported an enhancement of P2 andN1cAEPs evoked by musical tones and pure tones that have pitch-like quality in skilled musicians compared with control subjects who have not trained musically (Shahin et al., 2003a). There are studies to prove that older adults can benefit from musical training early in life which continues to have an effect on long term training driven plasticity (Skoe & Kraus, 2012; White-Schwoch, Carr, Anderson, Strait, & Kraus, 2013). Kraus et al. (2012) reported that the changes in the nervous system due to musical training for around 3 years in childhood could continue in the later stages of life even after the training is no longer continued. However, there are studies reporting that long term intensive training is required for musical training to have a positive effect on structural and well as functional changes in the nervous system, who in the study did not see a significant difference between the musicians and non-musicians (Moreno & Besson, 2006).

2.2 Linguistic skills

In one of the studies done by Jentschke and Koelsch (2009) they observed that musical training influences in the neurophysiological mechanism underlying the syntax processing in music and language in 10-to-11-year old children. They concluded that musically trained children had a more comprehensive knowledge of music-syntactic regularities. Studies have shown that musical training can also improve reading abilities in children when compared to children who have not undergone training (Moreno et al., 2009).

2.3 Speech perception in noise

Musicians have an advantage in a wide variety of auditory perceptual tasks. It has been proposed that the enhanced auditory skills developed through musical training could transfer to a better perception of speech in noise, as the neural structures involved in music and speech processing seem to partially overlap (Anderson & Kraus, 2011a; Besson, Chobert, & Marie, 2011b; Miendlarzewska & Trost, 2014). However, there are studies which show that such an effect could be minimal. In a study, measuring speech perception in steady or multi-talker babble noise showed either no, or only small, musician advantage (Parbery-Clark, Skoe, & Kraus, 2009). Başkent and Gaudrain (2016) studied the effect of musical training on SPIN and found that there was a strong musician benefit for speech perception in a speech masker. They also reported that the strong speech-on-speech perception advantage observed with musicians is not a direct result of better pitch perception, but instead it could be associated with other factors related to auditory perception, such as better stream segregation, better rhythm perception, or even better auditory cognitive abilities (Başkent & Gaudrain, 2016; Miendlarzewska & Trost, 2014).

In another study (Parbery-Clark, Skoe, & Kraus, 2009) they reported that musical experience results in the more robust subcortical representation of speech in the presence of background noise, which may contribute to the musician behavioural advantage for speech-in-noise perception. Also, studies have shown that musician enhancement for the perception and neural encoding of speech in noise arises early in life, with more years of training relating with more robust speech processing in children (Strait, Parbery-Clark, Hittner, & Kraus, 2012). They suggested that these perceptual and neural enhancements may be driven by the strengthening of auditory-specific cognitive abilities, such as auditory working memory and auditory attention.

Although various studies show that long term intensive training can have an influence on better perception, there are studies (Jain, Mohamed, & Kumar, 2015) that report that short term perceptual training of music resulted in improved speech perception in noise. In this study, they reported that even non-musician who had undergone short term training exhibited better scores in speech perception in noise tasks.

2.4 Pitch discrimination

Micheyl et al. (2006) reported enhanced pitch discrimination performance in musicians than non-musicians. They explained that the Carnatic musicians give more emphasis on correct tuning than other musical styles and that this emphasis on correct tuning promotes the development of more accurate pitch discrimination abilities(Micheyl et al., 2006). In another study (Kishon-Rabin, Amir, Vexler, & Zaltz, 2001) musicians obtained better frequency discrimination thresholds than non- musicians. And they reported that the performances varied with respect to musical genre and years of musical experience. They also found an improvement in DLF after very short training for musicians and non- musicians. And they hypothesized that the immediate dramatic improvements are probably due to cognitive factors. Results from another study (Besson, Schön, Moreno, Santos, & Magne, 2007) show that 6 months of musical training allowed children to detect small pitch changes in both speech and music. However, Moreno and Besson (2006) observed that 8 weeks of musical training did not show a significant difference from non-trained children. In summary, studies have demonstrated that musicians are superior to non-musicians in their ability to process pitch in speech (Chandrasekaran et al., 2009; Wayland, Herrera, & Kaan, 2010).

Chapter 3

Method

The aim of this present study was to evaluate the influence of Carnatic vocal musical training in children within the age range of 10 to 11 years old using Gap detection test, Temporal modulation transfer function, Dichotic CV, Speech perception in noise and Difference limen frequency and compare the results with that of musically non-trained children.

3.1 Participants

A total of 40 participants participated in the study. Participants were divided into two groups:

Group 1: Consisted of 20 children in the age range of 10-11 years with normal hearing sensitivity in both ears, who did not have vocal musical training.

Group 2: Consisted of 20 children in the age range of 10-11 years with normal hearing sensitivity in both ears, who were attending formal Carnatic vocal musical training for at least three years.

None of the participants had a history of hearing loss, ear discharge, trauma, ear disease. None of the participants reported any otological or neurological problems. All of them were native Malayalam speakers. Participants were randomly selected. Informed consent was given by the participant's parents before conducting the tests.

3.2 Testing environment

All the tests were carried out in a quiet room where the ambient noise was within permissible limits as recommended by ANSI S3.1 (1996).

3.3 Instrumentation

The following instruments were used in this study:

1. A laptop (Toshiba-satellite C850-B291) with MATLAB version 8.5.0 (2015) to present stimulus and record responses for psychoacoustical tests.
2. A Sennheiser HD 280 pro headphone connected to the laptop to present stimulus for psychoacoustical measures, SPIN and Dichotic CV test.

3.4 Materials

1. Psychophysical test: The stimuli for all the psychophysical tests were presented using mlp toolbox which implements maximum likelihood procedure for threshold estimation in MATLAB (Grassi & Soranzo, 2009).
2. SPIN: Speech recognition scores were obtained in the presence of noise for sentence in Malayalam developed by Sreeraj and Kishore (2014).
3. Dichotic CV: The stimuli were used from the list developed by Yathiraj (1999).

3.5 Stimulus and Procedure

All psychophysical tests were carried out using the mlp toolbox, which implements a maximum likelihood procedure for threshold estimation in Matlab (Grassi&Soranzo, 2009). The mlp calculates participant's psychometric function followed by each trial and estimates the responses for each trial. And this psychometric function which has the highest likelihood will decide the next stimulus to be presented. Thresholds were calculated for 30 trails. Stimuli were generated at 44,100 Hz sampling rate. Three intervals alternate force choice technique was used to estimate the threshold. Each trial consisted of three blocks wherein; two blocks had a standard stimulus and the third block had the variable stimulus which was presented randomly. Participants were instructed to identify the variable block from the three blocks of stimuli been presented. All the test stimuli were presented at 70 dBSPL binaurally where a Sennheiser HD 280 pro headphone. The headphone was calibrated using KEMAR connected to Bruel and Kjaer 2270 sound level metre.

Speech in noise test

Testing was conducted in a quiet room where the noise level was within permissible limits (ANSI-1996). The Malayalam sentences (Sreeraj & Kishore, 2014) was presented in the presence of 4 talker speech babble at 0 dB SNR using headphones connected to the laptop. A total of 30 sentences from 3 lists were presented, with 10 sentences in each list. Each sentence had 4 key words and each keyword carried a score of one. The participants were instructed to repeat back the sentences heard and every correct response repeated back were counted.

Dichotic listening test

For the dichotic CV test, the stimuli from the list given by Yathiraj (1999) were presented through headphones at 70dBSPL. After the presentation of the stimuli, subjects were asked to repeat back whatever they heard and the tester noted down the responses. Interval was given between every presentation. The test was administered at 0 ms lag, 30 ms lag (both right and left) and 90 ms lag (both right and left). The response was scored with respect to single correct scores (SCS) and double correct scores (DCS). SCS were given when the listener reported correct responses to the stimuli presented to one ear. DCS were given when the stimuli presented to both ears were repeated correctly.

Frequency difference limen

In this, the minimum frequency difference necessary to discriminate between two closely spaced frequencies were assessed. Pitch discrimination threshold for a 250 msec pure tones was tested at 500Hz, 1000Hz, 2000Hz and 4000Hz presented at 70 dB SPL. The onset and offset of tones were gated on and off with two 10 ms raised cosine ramps. On each trial of three blocks, two blocks consisted of pure tones at a standard frequency and other block consisted of a pure tone of variable frequency, which was always higher than the standard frequency. The participants were instructed to identify the variable block by either verbally reporting the number of the block or by pressing the key on the laptop. Frequency discrimination threshold estimated from a block of 30 trails.

Gap detection test

The participant's ability to identify a temporal gap in the centre of a 500 ms Gaussian noise was measured. A band of 500 ms Gaussian noise which had a gap in its temporal centre was presented using mlp toolbox through headphones connected to the laptop at 70 dB SPL. Three alternate forced choice interval technique was used to identify the thresholds. On each trial of three blocks, two blocks contained the standard noise which had no gaps and the third block contained noise which had a gap in the centre. The participants were instructed to identify the block which had noise with a gap and to either verbally report or to press the number key. The duration of the gap varied according to the listener's performance. GDT was estimated from a block of 30 trails.

Temporal modulation transfer function

In this, the minimum amplitude modulation necessary to identify amplitude-modulated noise from an un-modulated white noise was assessed. A 1000 ms Gaussian noise was sinusoidally amplitude modulated at modulation frequencies of 8Hz, 16Hz, 32Hz and 64Hz. The test was carried out using mlp toolbox and the stimulus was presented through headphones binaurally at 70 dB SPL. The minimum and maximum amplitude modulation was -30dB and 0 dB respectively. On each trial of three blocks, two blocks contained standard un-modulated noise and the third one contained the modulated noise which was presented randomly. The participants were instructed to identify the modulation and determine which block had the modulated noise. The threshold was estimated for a total of 30 trials per block using mlp toolbox.

3.6 Statistical analysis

The data were statistically analyzed using Statistical Package for Social Sciences (version 20). Descriptive statistics were used to estimate the mean and standard deviation of the data obtained in the study. One way repeated measures of ANOVA was carried out to analyse TMTF and DLF at different frequencies. Independent t-test was carried out to analyse GDT, SPIN and Dichotic CV test results.

Chapter 4

Results

The present study examined the effect of Carnatic vocal musical training on psychophysical abilities and speech perception in noise in children. A total of 40 children participated in the study with 20 children in the musically trained group and 20 in the musically non-trained group. Data followed normal distribution on Shapiro-Wilks normality test and hence parametric tests were used.

4.1 Speech perception in noise

Comparing the SPIN scores between musically trained and non-trained children addresses objective 1 of the study. SPIN scores were obtained by counting the total number of keywords repeated by the participants. Mean and standard deviation of SPIN scores across two groups are shown in Figure 4.1.

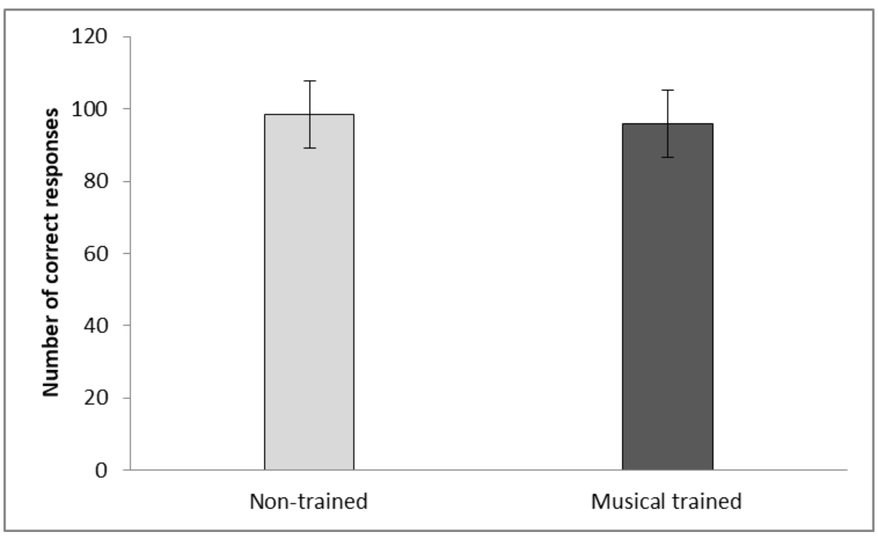

Figure 4.1: Mean and standard deviation of speech perception in noise scores of musically trained and non-trained groups. The maximum score possible is 120.

From Figure 4.1, it can be seen that SPIN scores were similar between the two groups. The results of Independent sample t-test were not significant, t (38)=0.834, $p>0.05$ indicating that there is no significant difference between the SPIN scores of the non-trained group (M= 98.40, SD= 9.35) and musically trained group (M=95.95, SD= 9.22).

4.2 Gap detection threshold

Figure 4.2 depicts the mean and standard deviation of GDT across both groups. From Figure 4.2, it can be seen that musically trained group had better GDT compared to the non-trained group. Furthermore, variability (as evidenced by SD) in GDT was higher in the non-trained group compared to the trained group. Independent sample t-test was carried out to see the significance of the difference in the GDT between two groups.

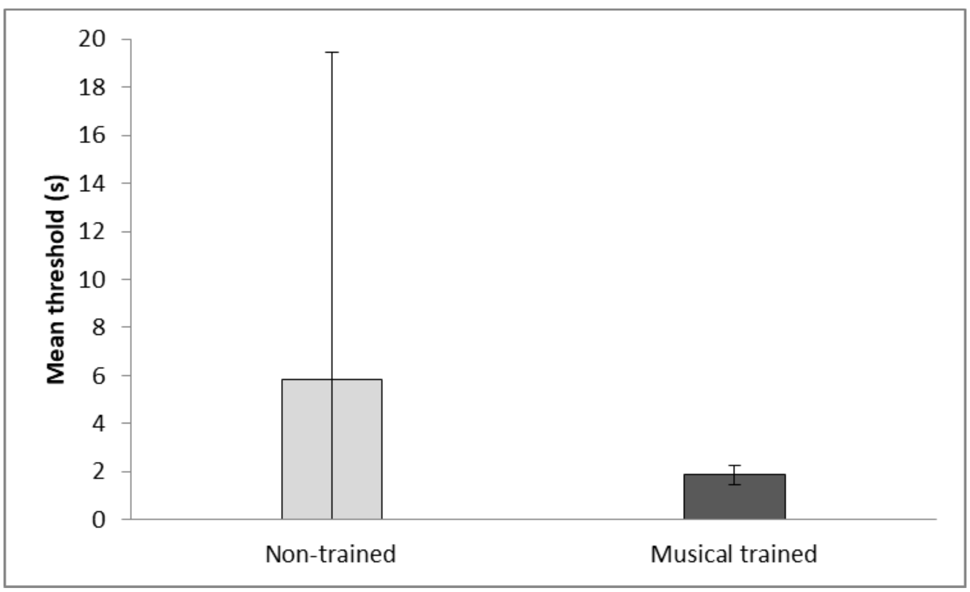

Figure 4.2: Mean and standard deviation of gap detection thresholds of musically trained and non-trained groups

The results of Independent sample t-test were not significant, t (38)=1.296, p>0.05 indicating that there is no significant difference between the GDT scores of the non-trained group (M= 5.83, SD= 13.63) and GDT scores of the musically trained group (M=1.88, SD= 0.404).

4.3 Dichotic CV test

Figure 4.3 shows the mean Single Correct Scores (SCS) of left and right ear and mean Double correct scores (DCS) of both the groups for 0ms lag stimulus.

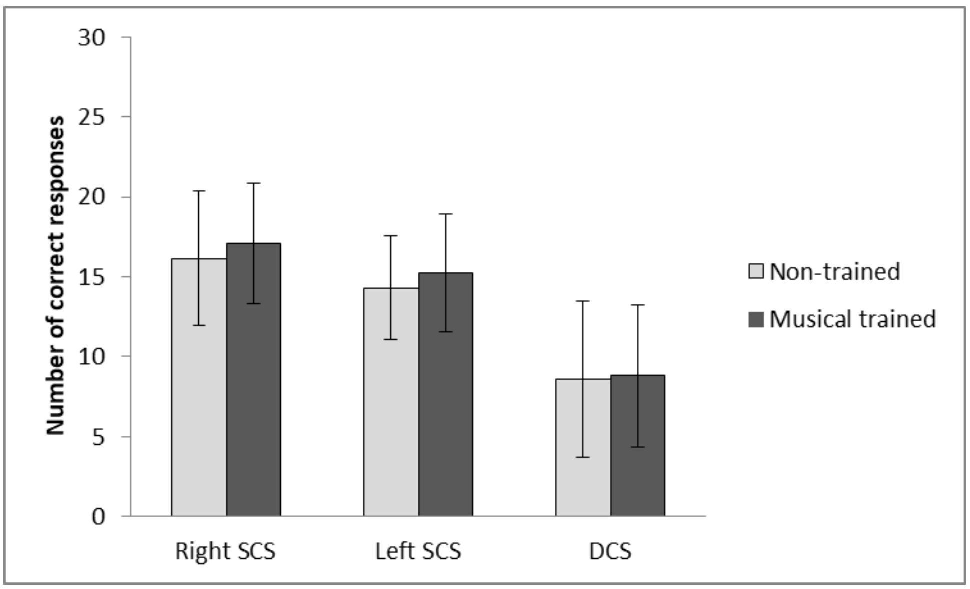

Figure 4.3: Mean and standard deviation of right and left single correct scores and double correct scores across both the groups using 0 ms lag stimuli.

From Figure 4.3, it can be inferred that the mean right SCS, left SCS and DCS for musically trained group (M=17.10, 15.25, 8.80; SD = 3.75, 3.66, 4.44 for right ear SCS, left ear SCS and DCS respectively) were similar to that of non-trained group (M= 16.15, 14.30, 8.60; SD= 4.18, 3.26, 4.88 for right ear SCS, left ear SCS and DCS respectively). Independent sample t-test revealed no statistically significant difference between two groups for right SCS [t(38) = 0.457, p>0.05], left SCS [t(38) = 0.392, p> 0.05] and DCS[t(38) = 0.893, p>0.05] between musically trained and non-trained groups. Figure 4.4 shows the mean and standard deviation of right ear and left ear SCS and DCS across both the groups for 30 msec lag stimuli.

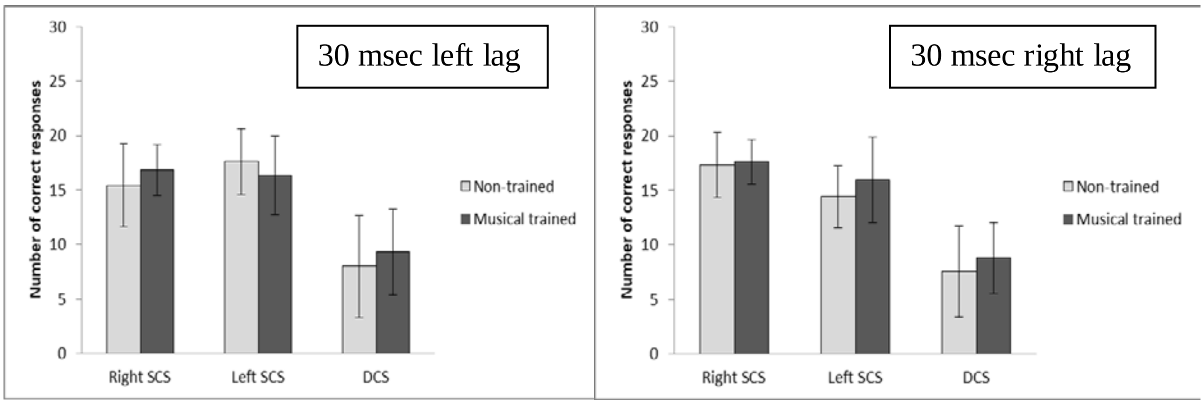

Figure 4.4: Mean and standard deviation of right and left single correct scores and double correct scores for 30 ms left lag and right lag stimuli.

From Figure 4.4, it can be noted that for 30 msec right lag stimulus, the mean and standard deviation for musically trained group (M= 17.60, 15.95, 8.80; SD = 2.03, 3.90, 3.22 for right ear SCS, left ear SCS and DCS respectively) were not different from that of non trained group (M= 17.35, 14.40, 7.55; SD= 2.96, 2.85, 4.19 for right ear SCS, left ear SCS and DCS respectively). Independent sample t-test revealed that the right ear SCS [t(38) = 0.757, p>0.05], left ear SCS [t(38) = 0.160, p> 0.05] and DCS [t(38) = 0.298, p>0.05] were not significantly different between musically trained and non-trained groups for 30 ms right lag stimuli.

For 30 msec left lag, the Independent sample t-test revealed that, scores were not significantly different for right ear SC [t (38)=0.154, p> 0.05], left ear SC [t(38)= 0.241, p>0.05] and DC scores [t(38)= 0.330, p> 0.05] between two groups. Figure 4.5 depicts the mean and standard deviation of the right ear and left ear SCS and DCS across both the groups for 90 msec lag stimuli.

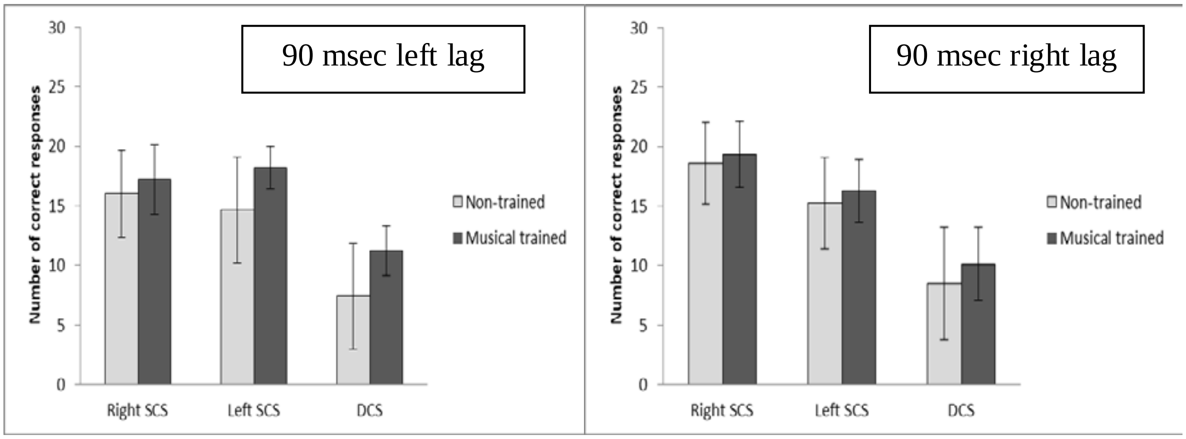

Figure 4.5: Mean and standard deviation of right and left single correct scores and double correct scores for 90 ms left lag and right lag stimuli.

Independent sample t-test revealed that the right ear SCS [t(38) = 0.454, p>0.05], left ear SCS[t(38) = 0.318, p> 0.05] and DCS [t(38) = 0.198, p>0.05] were not significantly different between musically trained and non-trained groups for 90 ms right lag. For 90 msec left lag stimulus, Independent sample t-test showed that there were no statistically significant differences in right ear SCS [t (38)=0.257, p> 0.05] between two groups. However, the test revealed a statistically significant difference in left ear SCS [t(38)= .002, p<0.05] and DCS [t(38)= .001, p<0.05] for 90 msec left lag stimulus between two groups. Musically trained children had significantly higher left SCS and DCS for 90 ms left lag stimulus.

4.4 Temporal modulation transfer function

Figure 4.6 shows the modulation detection thresholds across different modulation frequencies in musically trained and non-trained group. From the figure, it can be seen that the mean modulation detection thresholds were slightly better in the musically trained group, especially, at low modulation frequencies. To assess the statistical significance of these differences a One way repeated measures ANOVA was done. ANOVA revealed a significant main effect of modulation frequencies [$F(3,114)= 29.552$, $p<0.01$] and musical training [$F(1,38)= 2656.314$, $p<0.01$] on modulation detection thresholds. Follow-up independent samples t-tests between modulation detection thresholds of musically trained and non-trained groups were carried (with Bonferroni's corrections) out to check the statistical significance of mean differences. Results of the post-hoc analysis are shown in Table 4.1. From Table 4.1, it can be seen that there is no statistically significant difference between musically trained and non-trained group for all the modulation frequencies tested.

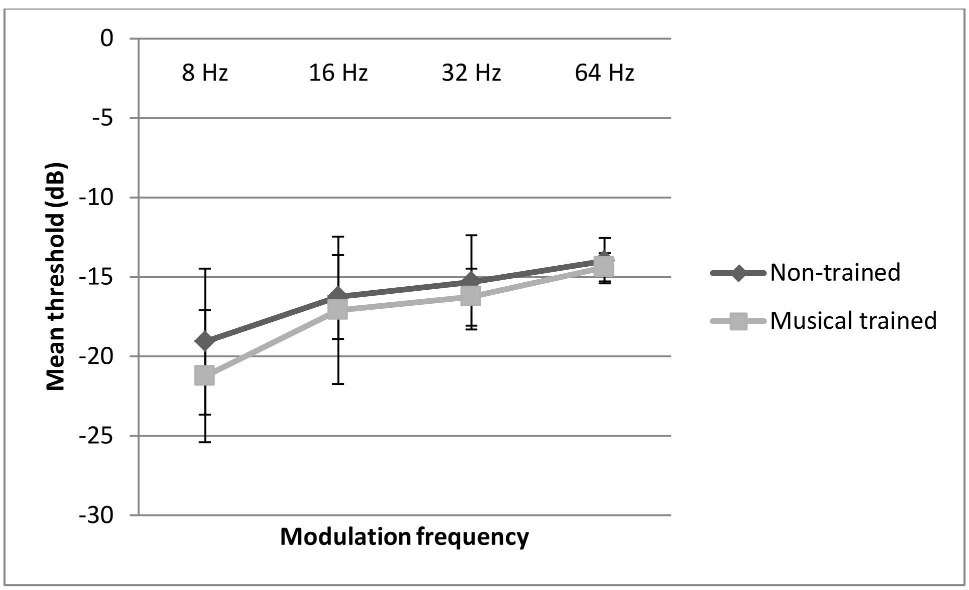

Figure 4.6: Mean and standard deviation of modulation detection thresholds across different modulation frequencies in musically trained and non-trained group

Table 4.1

Independent t-test results for temporal modulation transfer function

	8 Hz	16 Hz	32 Hz	64 Hz
t values	1.57	.715	1.206	1.12
Sig. (2-tailed)	.125	.479	.235	.268

4.5 Difference limen frequency

Figure 4.7 shows the mean frequency discrimination threshold and standard deviation of across different frequencies in musically trained and non-trained group. From the figure, it can be noted that the musically trained children had better frequency discrimination threshold compared non-trained children. To assess the statistical significance of these differences a One way repeated measures ANOVA was done. ANOVA revealed a significant main effect of frequencies [$F(3,114) = 16.55$, $p<0.01$] and musical training [$F(1,38) = 224.193$, $p<0.01$] on frequency discrimination thresholds. Follow-up independent samples t-tests between frequency discrimination thresholds of musically trained and non-trained groups were carried (with Bonferroni's corrections) out to check the statistical significance of mean differences. Results of independent samples t-test are shown in Table 4.2. From Table 4.2, it can be seen that musically trained children had significantly better frequency discrimination thresholds compared to non-trained children at all frequencies assessed.

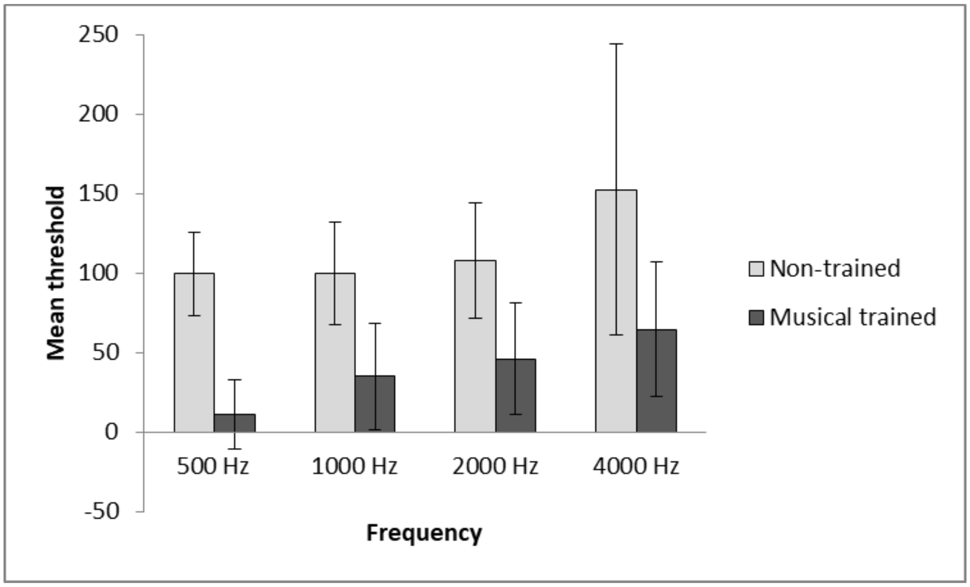

Figure 4.7: Mean threshold and standard deviation of difference limen frequency in musically trained and non-trained group across different frequencies.

Table 4.2

Independent t-test results for difference limen frequency

	500 Hz	1000 Hz	2000 Hz	4000 Hz
t value	11.56	6.28	5.43	3.89
Sig. (2-tailed)	.000*	.000*	.000*	.000*

Chapter 5

Discussion

The aim of the present study was to assess the effects of Carnatic musical training on psychophysical abilities and speech perception in noise in children within the age range of 10 to 11 years old. The result of the study are discussed below:

5.1 speech perception in noise

The results indicated that the SPIN scores did not differ significantly between the two groups (Figure 4.1). The scores of the musically trained and non-trained groups were almost similar indicating that there was no effect of musical training on SPIN in children taken up for the present study. In contrast, previous studies reported advantage for musician over non-musician in SPIN in adults (Başkent & Gaudrain, 2016; Parbery-Clark et al., 2009; Strait et al., 2012). Strait et al. (2012) revealed that there was a significant benefit of musical training on speech perception and the neural encoding of speech in noise in musicians. This musical training related benefit was positively correlated with the years of training. They postulated that these perceptual and neural enhancements may be driven by the strengthening of auditory-specific cognitive abilities, such as auditory working memory and auditory attention, with musical training. However, they did not see a difference between musicians and non-musicians in visual working memory and attention tasks. Baskent and Gaudrain (2016) also reported strong speech-on-speech perception advantage in musicians. Parbery-clark et al. (2009) studied the effect of musical experience on the neural representation of speech in noise in a group of trained musicians and compared it with non-musicians. Results showed that speech-evoked auditory brainstem responses were robust in the presence of noise in musicians. Musicians also had better speech perception in noise scores compared to non-musicians. They concluded that long-term musical experience could enhance speech in noise performance, working memory and frequency discrimination (Parbery-Clark et al., 2009). Furthermore, some studies have reported significant benefit in SPIN even with the short term musical training (Jain, Mohamed, & Kumar, 2015). Authors reported that, with short-term perceptual training (8 consecutive days), there was a significant improvement is SPIN scores.

However, a few studies have indicated no effect of musical training on SPIN. Boebinger, Evans, Rosen, Lima, Manly & Scott (2015) found no advantage for musicians' masked speech perception over that of non-musicians despite using similar target sentences and a co-located speech-spectrum steady-state noise masker as compared to other studies which have documented the positive effects of musical training. This study is in contrast with the study by Parbery-clark et al. (2009) where they reported enhanced performance in musicians. Parbery-clark et al. (2009) suggested that differences between groups may only arise when masking tasks require the greatest effort. The current study also showed no significant effect of musical training on speech perception in noise scores. This may be due to the less effort in the task where the SPIN scores were obtained using multi-talker babble at 0dBSNR. Also, there could be an influence of developmental aspects and duration of training.

5.2 Gap detection threshold

The results indicated that the GDT did not differ significantly between the two groups (Figure 4.2). This shows that there was no effect of musical training on GDT in the participants taken up for the present study which contraindicates with previous studies (Elangovan & Payne, Smurzynski, & Fagelson, 2016; Mishra & Panda, 2014). Mishra and Panda (2014) reported a significant group difference between musicians and non-musicians in GDT. They used across-channel GDTs to assess temporal processing. Authors suggested that measuring across-channel GDTs in Carnatic musicians may yield better results to prove that musicians have superior auditory temporal sensitivity (Mishra, Panda, & Herbert, 2014). Other studies are also in agreement with these findings (Elangovan et al., 2016). The present study assessed the effect of musical training using within-channel GDT rather than across channel GDT, which could be one of the reasons why both the groups had similar scores and showed no statistically significant difference. Zendel and Alain (2012) also did not observe significant differences in GDT between musicians and non-musicians. They suggested that there is an age-related factor that influences the performance as they observed an age-related decline in GDT. Musical training had minimal effect on the GDT as age progresses (Zendel & Alain, 2012). It can be hypothesized that age-related factor could also influence the performance as studies reported that child reaches adult-like performance in temporal processing by 10-11 years.

5.3 Dichotic CV test

The effect of musical training on dichotic CV test was assessed in 0 ms lag, 30 msec lag, and 90 msec lag conditions. Independent t-test revealed that in 0msec lag, 30 msec left lag, 30 msec right lag and 90 msec right lag stimuli, there was no statistically significant difference between musically trained and non-trained groups. However, there was a statistically significant difference seen in 90 msec left lag stimulus between musically trained and non-trained groups (Table 4.2). In a study (Nelson, Wilson, & Kornhass, 2008) the authors reported no significant effect of training on Dichotic CV, digit and chords tasks between musician and non-musician groups. But they found significant ear effects between groups. They suggested that both musicians and non-musicians performed similarly due to the difficulty of the tasks and of the probabilities of listening associated with the closed-set response of four items. Authors also suggested that subjects with more advanced musical aptitude use the right hemisphere more in language processing in comparison with the non-musical subjects (Milovanov & Tervaniemi, 2011). Milovanov et al. (2007) reported that only adults who performed well in the Seashore musical aptitude test and practised music regularly showed more accurate left ear monitoring skills when listening to Finnish CV-syllables. From these findings, it can be assumed that an enhancement in the performance of Dichotic CV tasks can be expected with more intense and long term practice in music. Also, it was observed that the listening task was too difficult for younger children and hence the differences may not be evident.

5.4 Temporal modulation transfer function

One way repeated measure ANOVA was done to see the significant difference between musically trained and non-trained group and thereby to see the effect of musical training on TMTF. The results showed that there was an effect of modulation frequencies (8Hz, 16Hz, 32Hz, and 64Hz) on the modulation thresholds and musical training. The modulations thresholds in the musically trained group were lower than the non-trained group. When the modulation frequencies increased from 8 Hz to 64 Hz, there was an overall increase in thresholds across both the groups. In order to see the difference between both the groups, independent sample t-test was carried out. The findings suggested that there were no statistically significant differences in modulation detection thresholds between musically trained and non-trained group across all the 4 modulation frequencies. It can be hypothesized that such findings could be attributed to developmental changes in children as the child attains maturity in temporal resolution skills not until 11 years (Hartley, Wright, Hogan, & Moore, 2000).

5.5 Difference limen frequency

Results showed a statistically significant difference between the musically trained and non-trained group in pitch discrimination across different frequencies of pure tones (500Hz, 1000Hz, 2000Hz and 4000Hz). The results revealed that musically trained children were able to differentiate pure tones which are more closely spaced compared to musically non-trained children. Similar results in children as well as in adults are reported by other investigators as well (Besson, Schön, Moreno, et al., 2007; Kishon-Rabin et al., 2001; Kumar, Sanju, & Nikhil, 2016; Magne et al., 2006; Micheyl et al., 2006; Wayland et al., 2010). In a study (Magne et al., 2006) they reported a lower percentage of errors in pitch processing tasks for musicians than for non-musicians in both music and speech. In contrast, Wayland et al. (2010) reported that musicians were not significantly better than non-musicians on the pitch discrimination task either before or after training, suggesting comparable pitch abstraction and categorization ability among the two groups. In the present study, the musically trained group showcased lower thresholds compared to that of the non-trained group. As the frequencies of the pure tones increased from 500 Hz to 4000 Hz, both the groups showed an increment in thresholds which shows that there was an effect of frequencies as well as musical training on DLF. A possible explanation for the difference in pitch discrimination performance between two groups is that classical music places more emphasis on correct tuning than other musical styles and that this emphasis on correct tuning promotes the development of more accurate pitch discrimination abilities (Micheyl et al., 2006)

Chapter 6

Summary and Conclusion

The present study was conducted with the aim to study the effect of Carnatic musical training on psychophysical abilities and speech perception in noise in children. A total of 40 children within the age range of 10 to 11 years were taken for this study. Participants were divided into two groups, where group 1 consisted of normal hearing children who are under musical training for at least 3 years and the group 2 consisted of children who did not have any formal musical training. Gap detection threshold, temporal modulation transfer function, and difference limen frequency were assessed using mlp toolbox implemented in MATLAB software. SPIN was measured by counting the number of words repeated from the list of Malayalam sentences in the presence of multi-talker babble at 0dB SNR. For the Dichotic CV test, listeners were asked to repeat back whatever they heard and responses were scored with respect to single correct scores and double correct scores. Results revealed that the musically trained group performed significantly better than the non-trained group in pitch discrimination task. A significant difference was not observed in TMTF, GDT, SPIN and Dichotic CV tests between both the groups. Through the finding of the present study, it can be concluded that Carnatic vocal musical training enhances pitch discrimination ability which could possibly due to the kind of training in Carnatic music where they focus more on identifying pitch contours. These results add to the findings in the existing literature that musical training facilitates pitch perception irrespective of whether its Indian classical music or western music.

Reference

Anderson, S., & Kraus, N. (2011, May). Neural encoding of speech and music: implications for hearing speech in noise. *Seminars in hearing* (Vol. 32, No. 02, pp. 129-141). © Thieme Medical Publishers.

Başkent, D., & Gaudrain, E. (2016). Musician advantage for speech-on-speech perception. *The Journal of the Acoustical Society of America*, 139(3), EL51-EL56.

Besson, M., Chobert, J., & Marie, C. (2011). Transfer of training between music and speech: common processing, attention, and memory. *Frontiers in psychology, 2, 94.*

Besson, M., Schön, 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(3-4), 399-410.

Boebinger, D., Evans, S., Rosen, S., Lima, C. F., Manly, T., & Scott, S. K. (2015). Musicians and non-musicians are equally adept at perceiving masked speech. *The Journal of the Acoustical Society of America*, *137*(1), 378–387. https://doi.org/10.1121/1.4904537

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), 1-9.

Devi, N., & Swathi, C. (2016). Effect of musical training on masking paradigm. *Indian Journal of Otology*, *22*(2), 85. https://doi.org/10.4103/0971-7749.182280

Elangovan, S., Payne, N., Smurzynski, J., & Fagelson, M. A. (2016). Musical Training Influences Auditory Temporal Processing. *Journal of Hearing Science*, 6(3), 37-44.

Estis, J. M., Dean-Claytor, A., Moore, R. E., & Rowell, T. L. (2011). Pitch-matching accuracy in trained singers and untrained individuals: the impact of musical interference and noise. *Journal of Voice*, 25(2), 173-180.

Fujioka, T., Ross, B., Kakigi, R., Pantev, C., & Trainor, L. J. (2006). One year of musical training affects development of auditory cortical-evoked fields in young children. *Brain*, *129*(10), 2593–2608. https://doi.org/10.1093/brain/awl247

Hartley, D. E., Wright, B. A., Hogan, S. C., & Moore, D. R. (2000). Age-related improvements in auditory backward and simultaneous masking in 6-to 10-year-old children. *Journal of Speech, Language, and Hearing Research*, 43(6), 1402-1415.

Herholz, S. C., & Zatorre, R. J. (2012). Musical training as a framework for brain plasticity: behavior, function, and structure. *Neuron*, 76(3), 486-502.

Hudziak, J. J., Albaugh, M. D., Ducharme, S., Karama, S., Spottswood, M., Crehan, E., … Botteron, K. N. (2014). Cortical thickness maturation and duration of music training: Health-promoting activities shape brain development. *Journal of the American Academy of Child and Adolescent Psychiatry*, *53*(11), 1153–1161.e2. https://doi.org/10.1016/j.jaac.2014.06.015

Hyde, K. L., Lerch, J., Norton, A., Forgeard, M., Winner, E., Evans, A. C., & Schlaug, G. (2009). Musical training shapes structural brain development. *The Journal of Neuroscience : The Official Journal of the Society for Neuroscience*, *29*(10), 3019–3025. https://doi.org/10.1523/JNEUROSCI.5118-08.2009

Jain, C., Mohamed, H., & Kumar, A. U. (2015). The Effect of Short-Term Musical Training on

Speech Perception in Noise. *Audiology Research*, *5*(1), 111. https://doi.org/10.4081/audiores.2015.111

Jain, S., Sahana, K., & Vinutha, M. M. (2016). Effect of Musical Training on Perception of Temporal Fine Structure Cues in Children. *Proceedings of the International Symposium "Frontiers of Research on Speech and Music (FRSM- 2016)"*, (November), 79–82.

Jentschke, S., & Koelsch, S. (2009). Musical training modulates the development of syntax processing in children. Neuroimage, 47(2), 735-744.

Kishon-Rabin, L., Amir, O., Vexler, Y., & Zaltz, Y. (2001). Pitch discrimination: Are professional musicians better than non-musicians?. *Journal of basic and clinical physiology and pharmacology*, 12(2), 125-144.

Koelsch, S., Fritz, T., Schulze, K., Alsop, D., & Schlaug, G. (2005). Adults and children processing music: An fMRI study. *NeuroImage*, *25*(4), 1068–1076. https://doi.org/10.1016/j.neuroimage.2004.12.050

Konadath, S., & Tanniru, K. (2014). *Sentence list in Malayalam and Telugu*. Unpublished independent project, University of Mysore, Mysore

Kraus, N., & Chandrasekaran, B. (2010). Music training for the development of auditory skills. *Nature Reviews Neuroscience*, *11*(8), 599–605. https://doi.org/10.1038/nrn2882

Kraus, N., Slater, J., Thompson, E. C., Hornickel, J., Strait, D. L., Nicol, T., & White-Schwoch, T. (2014). Music Enrichment Programs Improve the Neural Encoding of Speech in At-Risk Children. *Journal of Neuroscience, 34*(36), 11913–11918. https://doi.org/10.1523/jneurosci.1881-14.2014

Kumar, P., Sanju, H. K., Nikhil, J. (2016). Temporal Resolution and Active Auditory Discrimination Skill in Vocal Musicians. *International Archives of Otorhinolaryngology*, *20*(4), 310–314. https://doi.org/10.1055/s-0035-1570312.

Lorenzo, O., Herrera, L., Hernández-Candelas, M., & Badea, M. (2014). Influence of Music Training on Language Development. A Longitudinal Study. *Procedia - Social and Behavioral Sciences*, *128*, 527–530. https://doi.org/10.1016/j.sbspro.2014.03.200

Magne, C., Schön, D., & Besson, M. (2006). Musician children detect pitch violations in both music and language better than nonmusician children: behavioral and electrophysiological approaches. *Journal of cognitive neuroscience*, 18(2), 199-211.

Micheyl, C., Delhommeau, K., Perrot, X., & Oxenham, A. J. (2006). Influence of musical and psychoacoustical training on pitch discrimination. *Hearing research*, 219(1-2), 36-47.

Miendlarzewska, E. A., & Trost, W. J. (2014). How musical training affects cognitive development: rhythm, reward and other modulating variables. *Frontiers in neuroscience*, 7, 279.

Milovanov, R., & Tervaniemi, M. (2011). The interplay between musical and linguistic aptitudes: A review. *Frontiers in Psychology*, *2*-321..

Mishra, S. K., & Panda, M. R. (2014). Experience-dependent learning of auditory temporal resolution: evidence from Carnatic-trained musicians. *Neuroreport*, 25(2), 134-137.

Mishra, S. K., Panda, M. R., & Herbert, C. (2014). Enhanced auditory temporal gap detection in listeners with musical training. *The Journal of the Acoustical Society of America*, *136*(2), EL173-EL178. https://doi.org/10.1121/1.4890207

Mishra, S. K., Panda, M. R., & Raj, S. (2015). Influence of musical training on sensitivity to temporal fine structure. *International Journal of Audiology*, *54*(4), 220–226. https://doi.org/10.3109/14992027.2014.969411

Moreno, S., & Besson, M. (2006). Musical training and language-related brain electrical activity in children. *Psychophysiology*, 43(3), 287-291.plololp

Moreno, S., Marques, C., Santos, A., Santos, M., Castro, S. L., & Besson, M. (2008). Musical training influences linguistic abilities in 8-year-old children: more evidence for brain plasticity. *Cerebral Cortex*, 19(3), 712-723.

Nelson, D. M., Wilson, R. H., & Kornhass, S. (2008). Performance of Musicians and Nonmusicians on Dichotic Chords, Dichotic CVs, and Dichotic Digits. *Journal of the American Academy of Audiology, 14*(10), 536–544. https://doi.org/10.3766/jaaa.14.10.2

Pantev, C., Oostenveld, R., Engelien, A., Ross, B., Roberts, L. E., & Hoke, M. (1998). Increased auditory cortical representation in musicians. Nature, 392(6678), 811.

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*(45), 14100–14107. https://doi.org/10.1523/jneurosci.3256-09.2009

Sanju;, H. K., & Kumar;, P. (2016). Effect of Carnatic Vocal Music Training and Experience on Cortical Auditory Evoked Potential. *Journal of Hearing Science*, *6*(1), 40–47. https://doi.org/10.17430/895685

Sanju, H. K., & Kumar, P. (2016). Pre-attentive auditory discrimination skill in Indian classical vocal musicians and non-musicians. *Journal of Otology, 11*(3), 102–110. https://doi.org/10.1016/j.joto.2016.06.002

Schlaug, G., Forgeard, M., Zhu, L., Norton, A., Norton, A., & Winner, E. (2009). Training-induced neuroplasticity in young children. *Annals of the New York Academy of Sciences*, *1169*, 205–208. https://doi.org/10.1111/j.1749-6632.2009.04842.x

Schlaug, G., Norton, A., Overy, K., & Winner, E. (2005). Effects of music training on the child's brain and cognitive development. *Annals of the New York Academy of Sciences*, *1060*, 219–230. https://doi.org/10.1196/annals.1360.015

Shahin, A., Bosnyak, D. J., Trainor, L. J., & Roberts, L. E. (2003). Enhancement of neuroplastic P2 and N1c auditory evoked potentials in musicians. *Journal of Neuroscience*, 23(13), 5545-5552.

Shahin, A. J., Roberts, L. E., Pantev, C., Aziz, M., & Picton, T. W. (2007). Enhanced anterior-temporal processing for complex tones in musicians. *Clinical Neurophysiology,* 118(1), 209-220.

Skoe, E., & Kraus, N. (2012). A Little Goes a Long Way: How the Adult Brain Is Shaped by Musical Training in Childhood. *Journal of Neuroscience*, *32*(34), 11507–11510. https://doi.org/10.1523/JNEUROSCI.1949-12.2012

Strait, D. L., 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*(3), 661–668. https://doi.org/10.1111/j.1460-9568.2009.06617.x

Strait, D. L., Parbery-Clark, A., Hittner, E., & Kraus, N. (2012). Musical training during early childhood enhances the neural encoding of speech in noise. *Brain and language,* 123(3), 191-201.

Wayland, R., Herrera, E., & Kaan, E. (2010). Effects of musical experience and training on pitch contour perception. *Journal of Phonetics*, 38(4), 654-662.

White-Schwoch, T., Carr, K. W., Anderson, S., Strait, D. L., & Kraus, N. (2013). Older Adults Benefit from Music Training Early in Life: Biological Evidence for Long-Term Training-Driven Plasticity. *Journal of Neuroscience*, *33*(45), 17667–17674. https://doi.org/10.1523/JNEUROSCI.2560-13.2013

Whitton, J. P., Hancock, K. E., Shannon, J. M., & Polley, D. B. (2017). Audiomotor perceptual training enhances speech intelligibility in background noise. *Current Biology*, 27(21), 3237-3247.

Yathiraj, A. (1999). Dichotic CV Test-Revised. Mysore: Developed at Department of Audiology, All India Institute of Speech and Hearing.

Zendel, B. R., & Alain, C. (2012). Musicians experience less age-related decline in central auditory processing. *Psychology and Aging*, *27*(2), 410–417. https://doi.org/10.1037/a0024816