INFLUENCE OF MUSIC TRAINING ON THE AGE RELATED DECLINE IN SPATIAL HEARING AND TEMPORAL PROCESSING ABILITY

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CERTIFICATE

This is to certify that this dissertation entitled **'Influence of Music Training on the Age Related Decline in Spatial Hearing and Temporal Processing Ability'** is a bonafide work submitted in part fulfilment for degree of Master of Science (Audiology) of the student Registration Number: 18AUD030. 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.

Mysuru
July, 2020

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CERTIFICATE

This is to certify that this dissertation entitled **'Influence of Music Training on the Age Related Decline in Spatial Hearing and Temporal Processing Ability'** has been prepared under my supervision and guidance. It is also been certified that this dissertation has not been submitted earlier to any other University for the award of any other Diploma or Degree.

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DECLARATION

This is to certify that this dissertation entitled **'Influence of Music Training on the Age Related Decline in Spatial Hearing and Temporal Processing Ability'** is the result of my own study under the guidance of a faculty at All India Institute of Speech and Hearing, Mysuru, and has not been submitted earlier to any other University for the award of any other Diploma or Degree.

Mysuru, **Registration No. 18AUD030**

July, 2020

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Abstract

Background: *In order to enjoy the music, which usually contains multiple streams, the listeners must be able to perceptually separate the auditory streams. The role of musical training has been extensively studied in terms of many psychoacoustic skills including temporal processing, speech perception in noise, processing of prosodic and linguistic aspects of speech, auditory attention, and auditory stream segregation.*

Aim: *The aim of the present study is to find the influence of musical training in preserving the spatial hearing ability in individuals with and without formal musical training across different age groups.*

Method: *The study was carried out on 36 musicians and 36 non-musicians, aged 41-50, 51-60 and 61-70 years. Using ITD, ILD, GDT, VAS identification and SSQ questionnaire, the spatial hearing and temporal processing ability was compared between the two groups.*

Results: *Comparison of mean scores showed that the musicians performed better than the non- musicians on all the measures. Kruskal-Wallis test done for musicians separately revealed no effect of age for all the measures, while the same for non-musicians indicated no effect of age for three measures i.e. VASI, GDT and SSQ. However, for ITD and ILD the effect of age was observed, indicating differences in binaural cue processing with age.*

Conclusion: *Musicians had superior performance on perceptual tasks that do not require reference memory process, suggests that extensive music training may exert a positive effect on timing performance. Lower scores of non-musicians on the behavioural tests, compared with musicians, may be considered as their weak performance in spatial auditory and temporal processing. The results of the present study reconfirm the effects of aging on spatial auditory processing, such as localization especially in non-musicians.*

Key words: *Spatial hearing, Temporal processing, Musical abilities.*

Chapter 1

Introduction

Spatial hearing reflects the auditory system's ability to interpret or relate the sounds that reach the head through different spatial paths. The detection and monitoring of the position of an auditory object in three dimensional space is processed by the sophisticated auditory system. By means of spatial hearing, it is also possible for the auditory system to either orient the attention towards or away from a sound source (Culling & Akeroyd, 2010).

The spatial resolution of the auditory system is poorer by two orders in terms of magnitude when compared to visual domain which is confined only to frontal plane (Grantham, 1995). Hence, this ability of the auditory system to locate sound sources in all directions aids in decision making, identification and task performance (Smith, Lombard, & Shaba, 2012). Spatial hearing has unique importance in the ability to perceive speech in noise and reverberation (Takahashi, 2009), it aids in music perception, and facilitates exchange of ideas with the communication partner (Byrne & Noble, 1998).

With the help of binaural hearing which is underpinned by spatial hearing, humans are able to compare the signal at one ear relative to the signal at the other ear. These are in turn reflected in terms of interaural level difference (ILD) that is when the head diffracts the sound waves it causes a difference in intensity between the two ears and are important for localization of high frequency sounds above 1.5 kHz and the intensity difference between the two ears can go up to a maximum of 20 dB at 6 kHz (Grantham, 1995). The second cue for localisation of sounds in space is the interaural time differences (ITD) that is the time of arrival of signal between the two ears and it provides a major cue for localising the low frequency sounds up to 1.5 kHz (Brughera, Dunai, & Hartman, 2013). Hence, the ILD and ITD cues are the basis of all binaural processing and are fundamental to spatial hearing.

These binaural cues of ITD and ILD codes mainly for right-left localization, while the front-back localization is explained widely by spectral cues (Blauret, 1997; Hofman, Van Riswick, & Van Opstal, 1998). For a sine wave, the concrete cue of ILD is most useful at high frequencies, while the cue of ITD is most useful at low frequencies. The idea is termed as the ‘duplex theory’ where sound localization is based in the ITD at low frequencies and ILD at high frequencies (Rayleigh, 1907).

The primary cues for azimuth and elevation are usually said to be binaural and monaural respectively. It reflects the fact that the outer ear or the pinna acts like an acoustic cue. Its resonant cavities and geometry lead to the amplification of some frequencies and interference effects lead to attenuation of other frequencies. Moreover, its frequency response is directionally dependent.

The spectral cues otherwise called the pinna cues and monaural spectral cues that are introduced by the pinna at high frequencies are major cues for the perception of elevation, front-back distinctions, and monaural localization (Blauert, 1969/70, 1997; Hebrank & Wright, 1974; Weinrich, 1982; Musicant & Butler, 1984; Middlebrooks & Green, 1991; Middlebrooks, 1992, 1997; Shaw, 1997; Wightman & Kistler, 1997). These pinna cues also contribute to the extra-cranialization of sound sources (Plenge, 1974; Blauert, 1997). Vertical localization is made possible by the low-frequency cues (below about 3000 Hz) that are associated with head diffraction and torso reflections (e.g., Gardner, 1973; Algazi, Duda, & Avendano, 2001). The pinna is known to reflect the sounds that come from the front more effectively than for the sounds that come from above, thus resulting in a notch which is more pronounced for sound sources in front than for sound sources from above. Along with that, the length of the path difference changes with the elevation angle, and thus results in the frequency of the notch to move with elevation. Although there are disputes regarding what features are important perceptually, it is also well established that the pinna provides the primary cues for elevation.

In order to enjoy the music, which usually contains multiple streams, the listeners must be able to perceptually separate the auditory streams. The role of musical training has been extensively studied in terms of many psychoacoustic skills including temporal processing, speech perception in noise, processing of prosodic and linguistic aspects of speech, auditory attention, and auditory stream segregation. Zendel and Alian (2012) examined the effect of musical training on segregating simultaneously occurring sounds using mistuned harmonic perception task and measured event related potentials. Their results indicated that musical training significantly enhance the stream segregation abilities. Beauvois and Meddis (1997) investigated the time decay and auditory stream biasing and reported slower exponential decay of the time constant in musicians.

It has also been reported that musical training has lead to better auditory and speech processing abilities and thus musicians' exhibit better abilities in auditory perception when compared to non-musicians (Musacchia, Sams, Skoe, & Kraus, 2007). This better perceptual ability in musicians has known to be the positive outcome of music on the auditory system.

The psychoacoustic measures for frequency discrimination, also known as difference limen for frequency (DLF) compared between musicians and non-musicians have reported significantly smaller discrimination threshold for musicians (Rabin, Amir, Vexler, & Zaltz, 2001). In the same study they have reported that an instrumental musician has DLFs for pure-tones that are smaller by 50% than non-musicians, which is suggestive that extensive musical training influences auditory pitch discrimination. In another study done by Jain, Mohamed, and Kumar (2014), they reported that short term musical training had an effect in the identification of ragas but did not show any significant improvement in other auditory abilities such as frequency, intensity or temporal resolution. This could be because the efficiency of the neural system showed no improvement for performing the auditory tasks because of short term musical training.

In a study done by Kaplanis and Van Velzen (2012) they reported that the human auditory system is able to process the information of reverberation contained in the surrounding environment and that the musicians had better space perception abilities mainly in the vertical distance discrimination, which is a behaviour seen in individuals with blindness as reported in Wersenyi and Repas (2012).

1.1. Need for the study

There are remarkable improvements reported in several auditory skills in individuals with formal musical training which are otherwise deficient in inviduals without musical training. Studies in spatial processing have employed different psychophysical measures to study the spatial auditory processing. Among these psychophysical measures virtual acoustic space identification source (test of virtual source identification under headphones), interaural difference thresholds (ITD & ILD) are widely studied.

There are several studies that highlight the enhanced Difference Limen for Frequency (DLF) and Difference Limen for Intensity (DLI) in musicians. However, only few studies have shown the relationship between active auditory processing and spatial hearing among individuals with and without formal musical training. There is a dearth of literature to explore the combination of binaural processing, temporal processing and spatial hearing measures in musicians across different age groups. Hence, there is a need to develop and test the efficacy which can remediate these spatial processing difficulties.

Further, there is a need to find out the age until which these auditory perceptual tasks will be persevered by comparing the relationship in musicians across different age groups. Studies have indicated a decrement in localization ability as a result of aging. According to a study by Dobreva et al., (2011), they reported that the localization abilities in the elderly subjects was less than that in the young and middle-aged ones. They also reported a decrement in the elderly population on ITD-based localization in the range of 1250 to 1575 Hz, which was indicative of temporal processing disorder in them. Another study by Koehnke et al., (2001) reported a decrease in the ability of their elderly subjects in localization, and ITD/ILD differentiation with age. There are several factors which contribute to neural processing slowdown in elderly among which are loss of myelin integrity, prolonged neural refractory times, and eventually deficits in spectro-temporal processing (Anderson & Kraus,2013). Furthermore, implementation of subjective ratings (using Speech, spatial and qualities of hearing- SSQ questionnaire) gives scope for realization of spatial processing difficulties demonstrated by individuals without musical training in everyday listening situations/ environment.

Therefore, these behavioural measures were specifically chosen in the present study to comprehensively evaluate the spatial processing abilities in individuals with and without formal musical training.

1.2. Aim

The present study is aimed to find the influence of musical training in preserving the spatial hearing ability in individuals with and without formal musical training across different age groups.

1.3. Objectives

1. To measure and document the spatial processing abilities in individuals with and without formal musical training across the age groups on the following behavioral measures.
    - Test of spatial acuity using virtual source
    - Test of binaural processing [Interaural Level Distance (ITD) & Interaural Time Difference thresholds (ILD)]
    - Test of temporal processing [Gap Detection Threshold(GDT)]
    - Subjective ratings [Spatial sub-section of Speech Spatial Quality of hearing questionnaire (SSQ)]
2. To compare the spatial accuracy scores of virtual source identification, binaural processing, temporal processing, and subjective rating in individuals with and without formal musical training across the age groups.

1.4. Null Hypotheses

1. There is no statistically significant effect of musical training on behavioural measures of auditory spatial and temporal processing in individuals with musical training.
2. There is no statistically significant difference in spatial performance between Musicians and Non-musicians on measures of spatial acuity using virtual

sources, binaural processing (ITD & ILD thresholds), temporal processing (GDT), and subjective rating (SSQ ratings).

Chapter 2

Review of literature

Spatial hearing refers to the capacity of the auditory system to interpret or exploit the different paths by which sounds may reach the head (Culling & Akeroyd, 2010). Blauert (1997) points out that spatial audition embraces the relationships between the locations of auditory events and other parameters. Spatial hearing allows the listeners to not only orient attention towards or away from a sound source but also to characterize the nature of listening space (Grantham, 1995). Thus spatial hearing becomes a fundamental prerequisite for optimal functioning in complex environments. Studies on spatial hearing have focussed on understanding normal aspects of spatial hearing (acoustical basis, physiological basis, perception of spatial cues by adults- younger & older), stimulus related, task related and subject related factors influencing spatial processing. To understand spatial perception differences in individuals with and without formal musical training. Considering these issues with respect to the aim and objectives of the study, review of literature was done in the following areas.

2.1. Spatial hearing and related phenomena

- 2.1.1. Acoustic pathway
- 2.1.2. Auditory pathway

2.2. Behavioural / psychoacoustical methods employed to investigate spatial processing

2.3 Perception of spatial cues by adults (younger and older)

2.4. Spatial hearing in listeners with and without musical training

2.5. Factors affecting spatial hearing

- 2.5.1. Stimulus related
- 2.5.2. Procedure related
- 2.5.3. Subject related

2.1. Spatial hearing and related phenomena

Human listeners have adapted to a specialized tool of spatial hearing to explore the world. In order to accomplish spatial perception accurately by the auditory system, it must first analyse the spatial layout of the sound source in three dimensional space, second, must tag the sources to avoid confusion and lastly, ignore the unimportant ones. The perception of sound source in space can be understood from different perspectives. In terms of the location of the sound source in the physical space, the references are made with respect to direction and distance of the sound. The inference of the sound location is made with respect to single or multiple sources. In the multiple sources, the source can either be coherent (sound events occurring at same instant of time) or incoherent (sound events occurring at different points in time). Figure 2.1 represents the framework of reference for location of sound in physical space.

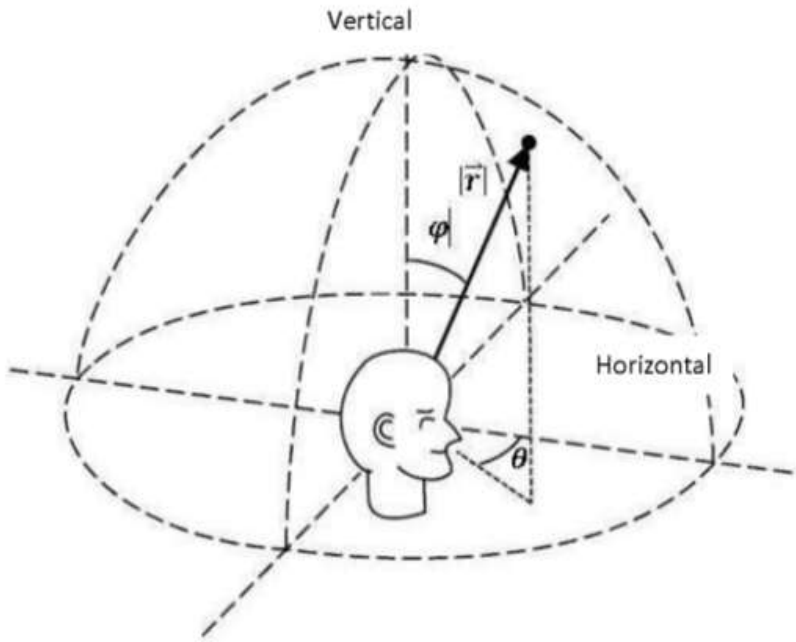

Figure 2.1. The framework of reference for location of sound in physical space. Source location in space is defined with azimuth (θ), elevation (φ), and distance along the horizontal and vertical planes (adapted from Blauert, 1997).

Another perspective of direction perception is explored in terms of the planes of reference with respect to the sound location i.e., horizontal and vertical plane. Horizontal plane primarily refers to the left or right spatial field, spanning either side of medial plane. On the other hand, vertical plane corresponds to the axis of localizing sounds along the medial plane i.e., detecting sounds or objects placed anywhere at the top or below the listener. Spatial perception of sound in the horizontal or vertical plane is commonly influenced by the following cues (Blauert, 1997; Xie, 2013).

(a) Inter-aural time difference (ITD)

(b) Inter-aural level difference (ILD)

(c) Spectral cues (pinna and torso cues)

(d) Direct to reverberation ratio (DRR)

(e) Sound intensity level

(f) Dynamic cues (head movement cues)

(g) Familiarity of sound source

(h) Visual and other non-auditory cues

Among these cues, ITD and ILD codes for azimuth, spectral cues aids in elevation, whereas the combination of DRR and sound level aids for distant perception (Grantham, 1995). The first five cues (a-e) relate to acoustic based cues while the last three relate to non-auditory cues.

2.1.1. Acoustic pathway

The acoustic signals arriving at the two ears are altered with respect to the locations of sound sources in human listeners. The parts of signals that can be used to compute the locations are called spatial hearing cues, which are broadly divided into two categories based on the physical characteristics of the listener.

Spatial sampling of the sound field. The two ears regarded as receptors are located at two different locations in space. The spatial distance between the receptors create a natural phase and time differences. The receptors are involved in sampling and collecting sounds typically at two physical points in acoustic space, resulting in the ITD.

Diffraction of sound by the human body. The sounds waves could be diffracted by objects with dimensions that are similar to their wavelength. The mid-frequency sounds (1-1.5 kHz) can be diffracted by the torso; high frequency sounds (2-3 kHz) can be diffracted by the head in addition to the torso (Zhong, 2015); still higher frequency sounds (4-17 kHz) are diffracted by pinnae (Shaw, 1997). These effects cue for monaural localization, ILD and head-related transfer functions (HRTF).

Inter-aural time difference. Since the 2 ears are separated by a relatively large head in between, there is a difference in the paths from the source to each of the ears which leads to a time difference across the ears which is termed as inter aural time difference**.**

Sound will reach the ear closer to source (near ear) than the ear which is far (far ear). This creates the time difference in reaching far ear and near ear. Inter aural time difference depends on size of the head and speed of the sound. Inter aural time difference is zero for frontally incident sounds and maximum for sounds coming from 90^0 with respect to the front. The psychoacoustical studies reported in literature estimate the ITDs threshold in humans to range from 10 to 670 µs (Blauert, 1997; Brughera et al., 2013; Klumpp & Eady, 1956). ITDs vary systematically with source azimuth (Kuhn, 1977), level (Nicolas Le Go, Jorg Buchholz, & DauForum, 2011) and duration of stimulus (Hafter & Maio, 1977; Tobias & Stanley, 1959). This time difference is important cue for localizing Low frequency up to 1500 Hz sounds because low frequencies have wavelength longer than the path around the head, so it bends around the head. The ITDs increase dramatically beyond 1 kHz in such a way that the listeners fail to perform ITD based sound localization beyond 1.4 kHz (Brughera et al., 2013).

Inter-aural level difference. When the signal is reaching the far ear, there will be more amount of reduction in intensity for higher frequency components of the sound whereas the low frequency components will suffer smaller amounts of reduction. This reduction is attributed to the wavelength of the two types of components i.e. wave length of high frequency signal is shorter when compared to low frequency signals. The resulting difference in level between the two ears is the ILD. ILDs too are known to vary with duration and level of the stimulus (Hafter, Dye, Nuetzel, & Aronow, 1977; Koehnke et al., 1995). They are also dependent on distance, angle and frequency of the stimulus (Brungart & Rabinowitz, 1999).

Spectral cues. While the ITD and ILD code for horizontal localization, the vertical localization is highly dependent on pinna based spectral cues. It is made possible by the reflections and resonances that occur within the pinna prior to the sound entering the ear canal. Because of these reflections and resonances, spectral peaks and notches are created at certain frequencies, which depend on the source elevation with respect to head. The resulting cues to localization in the mid sagittal vertical plane are all above 5000 Hz because it is only in this high frequency region that the wavelength of the sound is comparable to the size of the pinna, for necessary reflections and resonances.

Reflections of sounds are called as pinna echoes; sound from below will produce a slightly more delayed echo (about 300 microseconds), than if the sound came from above (echo after about 100 microseconds). The bumps and ridges of the outer ear apparently produce reflections of the entering sound. The delays between the direct path and the reflected path make vertical localization possible (Bear et al., 1996). Other than these, two other spectral cues are also usually implied in vertical-plane localization. These include the role of torso and interaural pinna disparity cue. The reflections from the torso are known to contain important spectral cues generally in the frequency range of 2-3 kHz (Grantham, 1995). The interaural pinna disparity cue provides useful information for frequencies above 8-10 kHz (Butler, Humanski, & Musicant, 1990; Middlebrooks et al. 1989; Searle, Braida, Davis, & Colburn, 1976).

Morimoto (2001) investigated the contribution of each pinna to the perception of vertical angle. Tests measured localization of the vertical angle in five planes parallel to the median plane. In the localization tests, the pinna cavities of one or both ears were occluded. Results showed that pinna cavities of both the near and far ears play a role in determining the perceived vertical angle of sound source in any plane, including the median plane. As a sound source shifts laterally away from the median plane, the contribution of the near ear increase and, conversely, that of the far ear decreases. For sagittal planes at azimuths greater than 60 degrees from midline, the far ear no longer contributes measurably to the determination of vertical angle.

2.1.2. Auditory pathway

The human hearing has a number of stages in the auditory spatial perception. Figure 2.2 represents a generic model of spatial hearing.

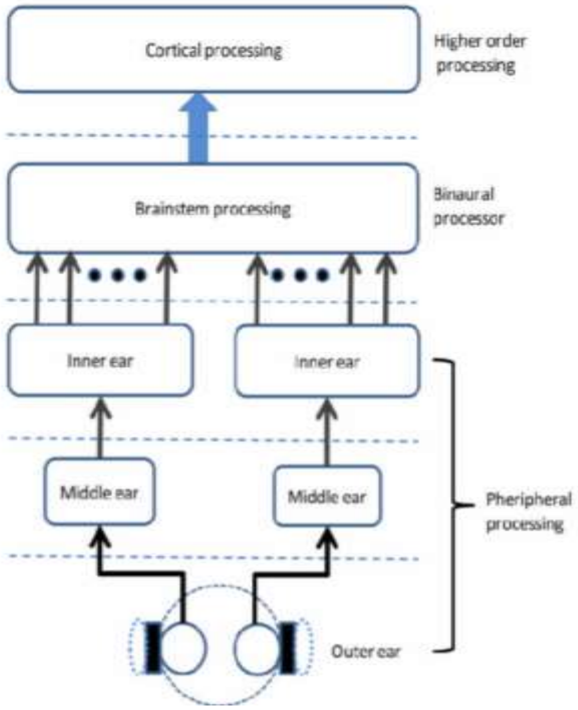

Figure 2.2. A generic model of spatial hearing. Adapted from Merimaa (2006).

The combined effect of the head, torso, and pinnae on sound can be measured, analysed and simulated through HRTFs (Algazi, Avendano, & Duda, 2001; Blauer, 1997; Wightman & Kistler, 1989). The HRTFs vary from individual to individual (Burge & Burger, 1999; Roebuck, Kroemer, & Thomson, 1975). The sounds transformed by the listener propagate through an efficient transmission system i.e., middle ear. The middle ear delivers it to the inner ear after converting sound energy into mechanical energy. The combined effect of the ear canal and the middle ear shifts the overall resonance peak of the ear from 3 kHz of the ear canal to 4 kHz (Blauert, 1997). The inner ear transduces sound signals to the neural pathways. The periphery only does the filtering and spectral decomposition of the signals with very limited role in spatial processing.

The spatial decomposition of the stimuli starts at the brainstem. The different acoustic cues are processed along independent neural pathways in the brainstem (Young & Davis, 2002). The lateral superior olive which is the lowest level in the brainstem contains neurons sensitive to ILD. The medial superior olive neurons on the other hand have been found to be sensitive to ITD (Goldberg & Brown, 1969; Yin & Chan, 1990). The spectral cues in spatial hearing (HRTFs) are processed by the dorsal division of the cochlear nucleus (DCN). This region also contains type IV neurons sensitive to the spectral notches in white band signals (Grothe, Pecka, & McAlpine, 2010). The neural pathway projects spatial information from type IV neurons of DCN to type O neurons in the inferior colliculus processes the directionally dependent spectral cues (Davis, Ramachandran, & May, 2003). Further, these processed spatial cues create a representation of where the object is located, in the central cortical mechanisms. There are at least two different modes of cortical representation in the superior colliculus (SC) and a distributed representation in the auditory cortex (AC) (Middlebrooks, 2015). The neurons in the SC respond maximally to sounds presented within a restricted region of space (Middlebrooks, 2015). Neurons in AC transmit information both with their spike counts and with the timing of spikes (Furukawa & Middlebrooks, 2002; Mickey & Middlebrooks, 2003).

2.2. Behavioural / psychoacoustical methods employed to investigate spatial processing

The investigations involving spatial acuity using real sources employ loudspeakers to replicate real life listening conditions, where all spatial cues of sound perception i.e., ITD, ILD, pinna and head effects are not compromised.

Source identification with the use of real sources is a popular method with variations in experimental details; for example, the loudspeakers can be visible (Dorman et al., 2016; Drennan et al., 2005; Lourenzi et al., 1999; Yost & Zhong,

2016) or concealed behind a curtain (Freigang, Schmiedchen, Nitsche, & Rubsamen, 2014; Keidser et al., 2006); the response can be verbally reporting the direction of the loudspeaker which delivers the sound (Neher et al., 2011) or giving the direction per se by pointing the hear toward the sound (Best et al., 2011).

Another method employed is the use of virtual acoustics to synthesize the direction with HRTFs. The HRTFs are captured through the microphones placed in the ear canal of the listener, using wideband signals from all directions. The flat wideband signals are converted into spectrally unique signals by the pinna, head, shoulders, torso etc., which act as filters. Thus, HRTFs basically describe how the sounds travel from specific point in space to the entrance of the ear canals (Wightman & Kistler, 1989). To simulate a sound coming from a given direction, the signals for each ear are convolved with the HRTFs to produce appropriate ITD, ILD, and spectral cues corresponding to the particular direction. Presentation of these modified signals over headphones will help create an illusion at the tympanic membrane as if the sound originated from a free-field environment. This particular illusion created using virtual acoustic space (VAS) stimulus is functionally same as that of the free-field sounds (Wightman & Kistler, 1989).

2.3 Perception of spatial cues by adults (younger and older)

The neural connectivity framed by experiences helps humans to understand where different sounds come from, separate events from one another, and to focus on the events that are relevant while attenuating others. Optimal spatial acuity forms the prerequisite for processing these events. Spatial acuity along with the properties of the sound relies with the dimensions of the head and external ears. Thus, during development, the cue values associated with any given direction in space will gradually change while these structures are growing. In addition, advancing age leads to changes in the anatomy and physiology of the inner ear including decline in number of outer hair cells, inner hair cells (Wright, Davis, Bredberg, Ulehlova & Spencer, 1987) and auditory nerve fibres (Makary, Shin, Kujawa, Liberman, & Merchant, 2011), poor blood supply to stria vascularis (Schmiedt, 1996), weaker endolymph potential (Schmiedt, 2010), poor inhibitory control of temporal acuity due to depleted neurotransmitters (Caspary, Milbrandt, & Helfert, 1995). Each of these factors or a combination of these factors is likely to show a negative impact on the spatial processing skills of older listeners.

There are many factors that hinder effective utilization of auditory spatial input and one of it is advancing age. According to a study done by Abel, Giguere, Consoli, and Papsin (2000), they reported that the spatial acuity declines with age and starts of by 40 years, even when hearing sensitivity is normal. Abel et al. (2000) also noted that the spatial acuity deterioration was more for the low frequency sounds of 500 Hz NBN (which is dependent on ITD processing) among the older adults. However, there was no association with ILD sensitivity as an effect of advancing age (Eddins & Hall, 2010). The study on binaural cue processing showed that elderly listeners required greater ITDs than young listeners to correctly lateralize a click, which no such group differences were seen when ILDs were used for the click lateralization (Herman, Warren, & Wagener, 1997). Babkoff et al. (2002) found that neither pure-tone nor click lateralization as a function of ILD, changed significantly as a function of ILD, changed significantly with age. However, lateralization of these stimuli as a function of ITDs became shallower with age. Changes in ITD produced 1.3 times smaller changes in perceived lateralization at 71 years compared to 25 years old.

The poor coding of ITD, ILD and IPD in older adults is reflected on their ability to localize sound in horizontal plane (Dobreva, Neill, & Paige, 2011). According to a study done by Freigang, Schmiedchen, Nitsche, and Rubsamen (2014) where they examined the effect of age on localization abilities for low frequency (375-750 Hz) and high frequency (2250-4500 Hz) noises in young (20-29 years) and older adults (65-83 years). They found that the rms errors increased from range of 4.1° to 11.1° in young adults a range of 4.3° to 13.7° in older adults for the low frequency noise. On the other hand, the rms errors for high frequency noise ranged from 4.5° to 13.7° in young adults compared to 4.9° to 17.8° in older adults.

2.4. Spatial hearing in listeners with and without musical training

Intense musical training for years together has been known to fine tune musicians auditory skills (Gaser & Schlaug, 2003; Munte, Nager, Beiss, Schroder & Altenmuller, 2003). Findings have also reported that musical training benefits auditory training not only in musical domain, but also in processing of speech stimuli (Musacchia et al., 2004; Wong, Skoe, Russo, Dees, & Kraus, 2007).

There also exist functional and structural differences in the auditory processing abilities between musicians and non-musicians and thus musical training influences temporal processing. As reported by Rammsayer and Altenmuller (2006) musicians were found to have superior temporal discrimination abilities than non-musicians. They reported that the temporal information processing is more accurate in musicians. A study was conducted on 24 musicians and non-musicians by Mohamdkhani, Nilforoushkhoshk, Mohammadi, Faghihzadeh, and Sepehrenejhad (2010). Results indicated that there was a significant difference in the scores between the 2 groups on GIN (Gap in Noise) test. They also concluded saying that the musicians had rapid temporal processing ability as they showed lower threshold in the

GIN test. The outcome of the study was attributed to the effect of musical training on central auditory processing. In another study conducted by Thomas (2011) wherein he investigated temporal resolution abilities in musicians using GDT and TMTF, the results revealed that the musicians had better temporal resolution abilities which became better as the years of musical training of the musicians increased. A similar study was conducted by Saha (2013) on temporal resolution abilities in mridangam players using TMTF and GDT; it was found that the mridangam players had better temporal resolution abilities. It was reported that musical training contributed to better performance in musicians.

Several studies (Emmeric, Rudel, & Richter, 2008; Jansen, Hellman, & Laat, 2009) indicated that the prevalence of hearing loss in professional musicians to be 38-50%. However, there are few contradictory studies which reported that exposure to music is not oto-traumatic (Karlsson, Lundquist, & Olaussen, 1983; Johnson, Sherman, Aldridge, & Lorraine, 1985). Music generally being accepted to be intermittent reduces the probability of causing hearing loss in musicians when compared to industrial workers exposed to noise (Chasin, 2008).

2.5. Factors affecting spatial hearing

The listener is vastly dependent on two set of cues in order to perform the spatial hearing tasks. One set of hearing cues that a listener uses to interpret are the acoustic cues and the second set of cues are related to factors such as stimulus related (duration, frequency, type of stimulus), task related (uni v/s multi-sensory processing, role of distracters, types of learning, feedbacks) and subject related (motivation, memory, and attention).

2.5.1. Stimulus related factors. Majdak, Walder, and Laback (2013) studied the effect of type of stimulus on source localization. They used broad band limited (up to 8.5 kHz) and spectrally wrapped (from the range between 2.8 and 16 kHz to the range between 2.8 and 8.5 kHz) noises and found that localization errors were highest for the wrapped (44.5°) stimuli. The localization errors decreased for band limited (39.8°) stimuli, whereas the broadband (32.9°) stimuli was the easiest to localize. The frequency of stimulus band can also influence spatial processing. Frequency of stimulus band determines the kind and extent of spatial cues used (1-16 kHz in Carlile, Leong, & Hymas, 1997, and 1-3 kHz in Lewald & Ehrenstein, 1998).

The acoustic dimensions of stimulus such as intensity and duration alter sound localization (Hofman & Van Opstal, 1998; Macpherson & Middle brooks, 2000; Vliegen & Van Opstal, 2004). Macpherson and Middlebrooks (2000) found that participants in their study found high level clicks (86 dB SPL) to be more difficult to localize than the clicks which were presented at intermediate (74-86 dB SPL) level, which in turn were more difficult to localize than lower level (68-80 dB SPL) clicks.

2.5.2. Procedure related factors. The type of responses that are used in the task are generally accepted as a factor contributing to the magnitude of spatial errors. The responses for sound localization are mainly classified into four (Comalli & Altshuler, 1980), namely kinaesthetic (e.g., pointing with a laser), visual (e.g., referring to a map or to numbers located at various positions on a screen), auditory (e.g., loudspeaker on a boom), and verbal (e.g., estimating the angle). Carlile et al. (1997) compared different pointing techniques and concluded that head (nose) pointing was more accurate than verbal estimates or the use of a stylus with a tablet. Majdak et al. (2010) compared hand and head (nose) pointing and found similar localization performance for both methods in horizontal and vertical localization tasks. On meta-analyses of localization studies, Djelani, Porschmann, Sahrhage, and Blauert (2000) concluded that methods involving pointing toward the sound source or verbally indicating its position are generally more specific than system specific responses such as using a display screen, drawings on paper, etc. this was true for naïve listeners, with no or minimal experience in using the specific pointing system.

2.5.3. Subject related factors

There are various environmental and intrapersonal variations that affect spatial hearing. Variations in clothing, headwear, hair, and complex interactions with the surroundings all produce changes to the available spectral features (Treeby, Pan, & Paurobally, 2007). The shift in sound location judgments was modulated by handedness of the listener (Ocklenburg, Hirnstein, Hausmann, & Lewald, 2010). Ocklenburg et al. (2010) a shift was observed for left-handed listeners ie., rightward and a vice-versa for right-handed listeners ie., leftward.

Other factors such as listener's eye position during the localization task can also affect spatial perception (Razavi, O'Neill, & Paige, 2007). The influential role of the direction of gaze on neural processing and perception of auditory spatial information is also documented in literature (Bulkin & Groh, 2006; Zwiers, 2004), with large degree of variability across subjects (Populin, 2008). In addition, the role of other senses such as proprioception and vestibular kinetics are also indicated in perception of object location (Goossens & Van Opstal, 1999; Vliegen, 2004).

Chapter 3

Method

The present study is aimed to find the effect of musical training in preserving the spatial hearing ability in individuals with and without formal musical training across different age groups on various behavioral measures of spatial acuity. The study also compared the spatial accuracy scores of virtual source identification, binaural processing, temporal processing, and subjective rating in individuals with and without formal musical training across the age groups.

3.1. Selection of participants

A standard group comparison involved 36 trained musicians in each of the following age group that is in the age range of 41-50 years, 51-60 years and 61-70 years (12 in each age range) with each of them currently having a minimum musical training of 5 years and 36 matched typical participants with no formal training or informal training in music.

3.1.1. Inclusionary criteria & Exclusionary criteria

Inclusionary criteria.

To be included in the study, the participants are required to have:

- Formal musical training for at least 5 years
- Practices music for at least 9 hours per week
- Hearing sensitivity within <25 dB HL
- No previous exposure to psychoacoustical tests
- No history of otological or neurological problems
- Minimal cut-off score of 24-30 in Mini Mental State Examination to rule out the presence of cognitive decline

Exclusionary criteria.

Subjects with any abnormality in auditory system, neurological problems and psychological problems were excluded.

3.2. Test environment

All the participants were subjected to tests in an acoustically treated room which meets the ambient noise level criteria specified by ANSI S3.1-1999 (R2008).

3.3. Equipment and Materials

To carry out pure-tone audiometry, speech audiometry and to rule out any hearing loss, a calibrated two channel diagnostic audiometer with TDH-39 headphones and B-71 bone vibrator was used. A normal middle ear functioning was ensured using a calibrated immittance meter. Additionally, a laptop with MATLAB was utilized to present the stimulus for the tests of binaural processing and temporal processing. Mini Mental State Examination test was administered on all the participants as a screening task to rule out cognitive decline.

3.4. Procedure

Participants fulfilling the selection criteria were included in the study. The testing involved the comprehensive evaluation of spatial processing skills using behavioral measures in listeners with and without formal musical training. Behavioral tests included test of spatial acuity using virtual sources under headphones (VAS identification test), binaural processing (thresholds of ITD and ILD), temporal resolution (GDT) and administration of spatial sub-section of SSQ questionnaire.

The behavioral tests of spatial acuity were administered on both the group of participants. All the behavioral tests used in the study were conducted using 250 ms of WBNs which were identical in terms of overall level (80 dB SPL) as well as bandwidth. WBNs contain the full range of acoustic cues which are necessary for accurate location perception (Carlie, 2014; Kulkarni & Colburn, 1998). Also, the short duration of WBN signal (50 ms) prevents the listeners from using other cues such as exploratory head movements for real source location and/or inattentiveness and fatigue listening to long duration signals (Brungart et al., 2017). Therefore, WBNs were used to assess the auditory spatial abilities.

3.4.1. Test of temporal resolution [Gap Detection Threshold (GDT)]. Gap detection test consisted of a standard stimulus of 750 msec duration of Gaussian noise with a silence which is placed at its temporal centre. The gap duration which is variable was placed in the variable stimulus and the length of the gap was changed as a function of the subject's performance. The gap detection threshold was obtained using Three Interval Alternate Forced Choice Method (3IAFC) method. It consisted of 3 blocks of white noise, one of which contained gaps of variable duration. The subject's task was to identify the block which has the gap in it. The stimulus was presented at 40 dBSL (relative to PTA) or at the comfortable level. Each time the subject detects the gap embedded in the noise correctly, the size of the gap was reduced until the subject can identify the smallest gap in the noise. The minimum gap the subject can identify was thus considered as the gap detection threshold.

3.4.2. Test of binaural processing [Interaural Latency Difference (ILD) and Interaural Time Difference (ITD)]. The ILD and ITD thresholds were assessed using Three Interval Alternate Forced Choice (3IAFC) method employing two up one down transformed staircase method. The standard stimulus was a 250 msec WBN which was presented at 80 dB SPL while the variable stimulus of same duration was presented at a starting level of 20 dB SPL higher in one ear for the ILD task. On the other hand, the variable stimulus for ITD task started with a time delay of 30 msec in one ear and was presented at an intensity of 80 dB SPL. The subjects were asked to indicate the variant interval by pressing the number corresponding to the same on the keyboard. The time or level of the variant stimuli was varied in accordance to the response of the subject. The test was terminated after 10 reversals and the last 4 reversals were averaged to get the ILD and ITD threshold.

3.4.3. Tests of spatial acuity using virtual sources under headphones [Virtual Acoustic Spatial Identification (VASI test)]. VAS stimuli are sound percepts created within the head causing the illusion of natural free-filed sound using a closed-field sound system such as headphones (King et al., 2001). The stimulus was generated using sound module of Sound Lab version 6.7.3. The stimulus composed of 250 msec WBN. The stimuli generated were presented under headphones to create eight VAS perceptive., mid-line front (0° azimuth), mid-line back (180° azimuth), 45° azimuth towards the right ear, 90° azimuth towards the right ear, 135° azimuth towards the right ear, 45° azimuth towards the left ear, 90° azimuth towards the left ear, 135° azimuth towards the left ear. All the stimuli had a constant elevation of 0° azimuth and distance of 1m. Presentation and collection of the responses was controlled using Paradigm experimental builder software. The user interface consisted of a display of dummy head with eight locations corresponding to the eight VAS stimuli. Stimuli were randomly presented at these virtual locations using the software. Figure 3.1 represents the dummy head interface used for stimulus response acquisition in VASI test.

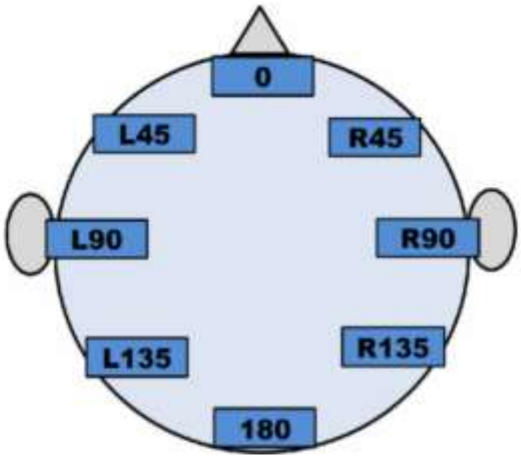

Figure 3.1. Pictorial representation of dummy head interface used for stimulus response acquisition in VASI test.

The VASI test was carried out in two sub-parts wherein the part I is the familiarization phase, while part II is the testing phase. In the familiarization phase, the subjects were encouraged to get familiar with the VAS stimuli using a practice run. In the testing phase, the stimulus corresponding to each virtual location was presented 10 times in a random sequence. The subjects were asked to attend to the VAS stimuli and click the mouse pointer on the position of dummy head, corresponding to the perceived location in the head.

Scoring. The responses of the individuals were directly entered in an excel sheet by the software at the end of the testing and were saved automatically in the name entered before the test was started. The column on the excel sheet contain information about the stimulus that was presented and the response of the individual. All the correct responses are scored as 1, whereas the incorrect responses are scored as 0.

3.4.3. Subjective rating scale (SSQ). The spatial sub-section of the speech, spatial, and quality of hearing (SSQ) questionnaire (Gatehouse & Noble, 2004) adapted to Indian situations (Hemanth, Chambayil, Syeda, & Vinodhini, 2019) was also administered on all the participants. The sub-section on spatial processing consists of seventeen questions on an eleven-point rating scale which taps on the localization difficulties involved in everyday listening situations. Each item of the scale is scored from 0 to 10; where 0 represents minimal ability and 10 represents complete ability. All the participants were instructed to rate each item under this sub-section.

Chapter 4

Results

The present study aimed to explore the differences in auditory spatial processing between individuals with and without formal musical training using behavioural measures. The study also aimed to document the changes in spatial processing abilities in musicians and non-musicians across different age groups i.e., 41-50 years, 51-60 years and 61-70 years.

The following statistical analysis was done across the group.

- Descriptive statistics was done to estimate the mean, median, min, max and inter-quartile range for all the tests.
- Kruskal-Wallis test was done between musicians and non-musicians to find the significant difference across the entire test.
- Mann-Whitney U test was done across two different age groups to find the significant difference among the various tests with age.

Results of the study are reported under following headings.

Section 4.1. Performance of individuals with and without formal musical training on auditory spatial processing.

Section 4.2. Performance of individuals with and without formal musical training on auditory spatial processing across different age groups.

Section 4.1. Performance of individuals with and without formal musical training on auditory spatial processing.

This section addresses the first objective of the study. This section documents and compares the performance of musicians and non-musicians on behavioural measures of spatial processing in auditory domain. The behavioural measures included in the study were- test of spatial performance using virtual sources (virtual space identification test), test of binaural processing abilities (interaural time & level difference- ITD & ILD), test of temporal resolution (gap detection threshold- GDT) and subjective rating of spatial difficulties (assessed using spatial sub-section of speech, spatial, & qualities of hearing- SSQ questionnaire).

Performance of two groups on range of auditory spatial processing skills were evaluated using virtual sources under headphones (virtual acoustic space identification: VASI test), test of binaural processing abilities (ITD & ILD), test of temporal resolution (GDT) and subjective rating of spatial difficulties (assessed using spatial sub-section of SSQ questionnaire). Table 4.1, 4.2 and 4.3 shows the result of descriptive statistics (mean, median, minimum, maximum and inter-quartile range) for various behavioural auditory spatial skills evaluated in the study between two groups across the age groups i.e., 41-50, 51-60 and 61-70 years respectively.

Table 4.1.
Auditory spatial performance of musicians and non-musicians on behavioural measures of spatial acuity used in the present study for the age range of 41-50 years.

Behavioural measures	**Mean**		**Median**		**Min**		**Max**		**Inter-quartile range**	
	M	*NM*	*M*	*NM*	*M*	*NM*	*M*	*NM*	*M*	*NM*
VASI score	41.0	28.16	39.5	29.5	28.0	19.0	50.0	38.0	15.5	8.50
ITD threshold (ms)	0.22	0.96	0.16	1.12	0.05	0.43	0.35	1.57	0.20	0.84
ILD threshold (dB)	2.35	2.56	2.29	2.55	2.12	2.25	2.75	2.75	0.27	0.25
GDT threshold (ms)	3.14	4.17	3.26	4.36	2.35	3.28	3.45	5.21	0.44	0.95
Subjective rating scores	161.8	109.1	162.5	106.0	145	100.0	170	138.0	13.0	13.75

Table 4.2.
Auditory spatial performance of musicians and non-musicians on behavioural measures of spatial acuity used in the present study for the age range of 51-60 years.

Behavioural measures	**Mean**		**Median**		**Min**		**Max**		**Inter-quartile range**	
	M	*NM*	*M*	*NM*	*M*	*NM*	*M*	*NM*	*M*	*NM*
VASI score	42.5	32.8	43.0	31.0	32.0	25.0	51.0	44.0	11.0	10.75
ITD threshold (ms)	0.32	0.48	0.34	0.43	0.05	0.38	0.45	1.12	0.07	0.06
ILD threshold (dB)	2.37	3.22	2.28	3.35	2.22	2.54	2.75	3.55	0.27	0.63
GDT threshold (ms)	3.24	4.41	3.22	4.61	3.12	3.14	3.44	4.76	0.26	0.54
Subjective rating scores	156.5	112.5	158.0	110.0	145	102.0	160	131.0	5.75	13.0

Table 4.3.
Auditory spatial performance of musicians and non-musicians on behavioural measures of spatial acuity used in the present study for the age range of 61-70 years.

Behavioural measures	**Mean**		**Median**		**Min**		**Max**		**Inter-quartile range**	
	M	*NM*	*M*	*NM*	*M*	*NM*	*M*	*NM*	*M*	*NM*
VASI score	39.4	32.4	39.5	32.0	30.0	25.0	57.0	41.0	27.0	5.25
ITD threshold (ms)	*0.36*	*0.88*	*0.24*	*1.12*	*0.15*	*0.34*	*1.14*	*1.25*	*0.19*	*0.82*
ILD threshold (dB)	2.38	2.81	2.42	2.77	0.34	2.12	1.25	3.50	0.82	0.50
GDT threshold (ms)	3.04	4.53	3.30	4.58	2.35	4.21	3.92	4.80	0.84	0.30
Subjective rating scores	156.7	111	157.0	107.5	153	102.0	160	117.0	5.50	5.00

From Table 4.1, 4.2 and 4.3 it can be inferred that individuals with musical training demonstrated better virtual space identification accuracy and better binaural cue processing and temporal processing (indicated by better ITD, ILD and GDT thresholds) compared to non-musicians. The better performance is evident in the above psychoacoustic measures was also seen in subjective rating scale, wherein non-musicians gave lower ratings for the items in spatial sub-section of SSQ questionnaire. The median and inter-quartile range for each of the behavioural measures among Musicians and Non-musicians are represented in Figure 4.1.

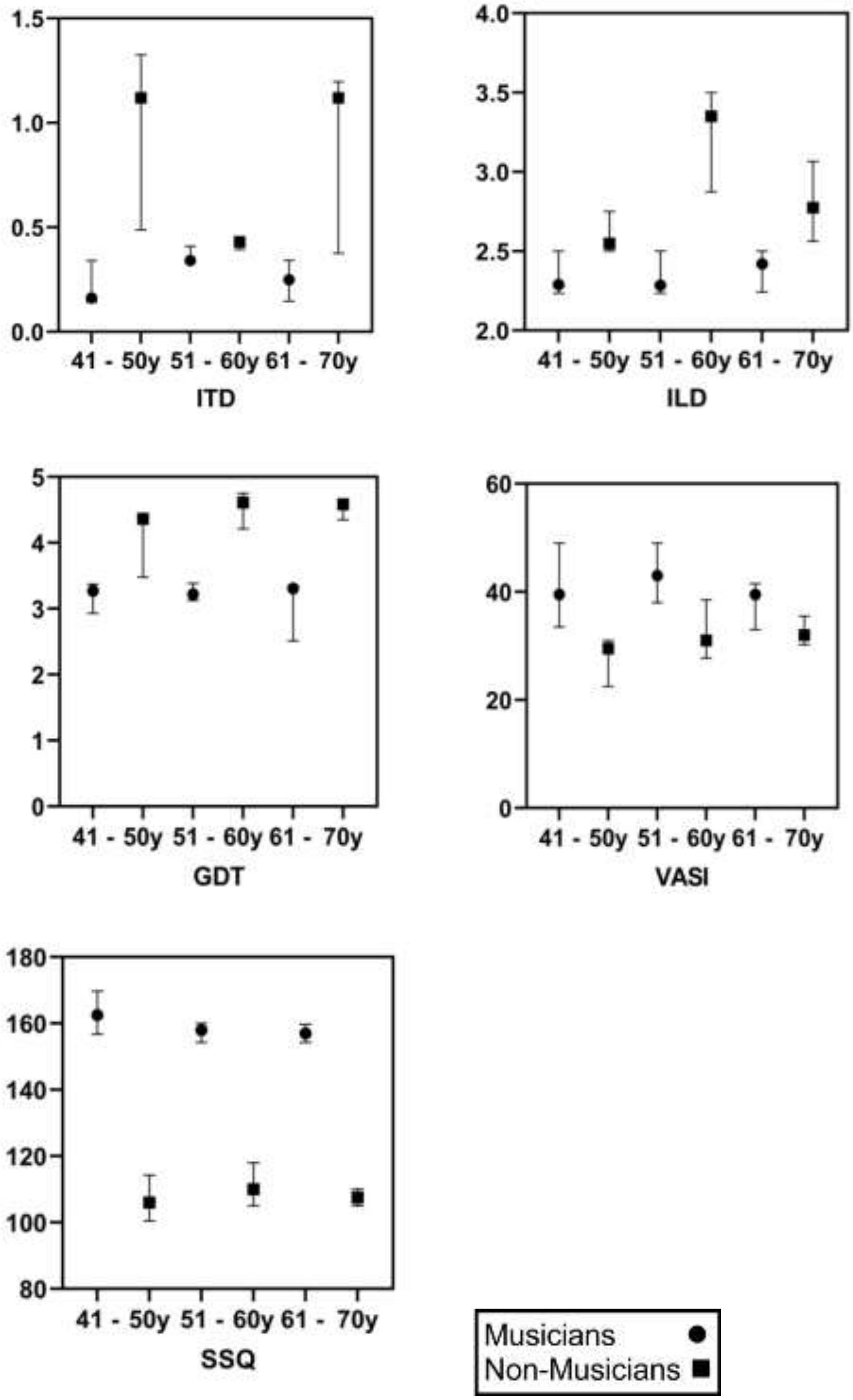

Figure 4.1. Represents the median and inter-quartile range for each of the behavioural measures among Musicians and Non-musicians.

All the behavioural measures of spatial acuity followed non-normal distribution (as revealed by Shapiro Wilk's test of normality, $p<0.05$). Hence, Mann-Whitney U test was carried out to compare musicians and non-musicians within each age group for all the behavioural measures. The results revealed that the effect of musicianship showed that all the tests effectively distinguished musicians from non-musicians, with musicians outperforming non-musicians in all tasks. The results of the same are depicted below in Table 4.4.

Table 4.4.
/Z/ scores along with the level of significance between musicians and non-musicians across the three age groups.

Behavioural measures	***41-50 years***	***51-60 years***	***61-70 years***
ITD	4.161*	3.179*	3.208*
ILD	2.613**	4.002*	2.554**
GDT	3.754*	3.701*	4.166*
VASI	3.387***	3.015***	2.350**
SSQ	4.167*	4.175*	4.185*

*p< 0.001, **p< 0.01, ***p< 0.005

From table 4.1 to 4.4, it can be seen that individuals with formal musical training performed significantly better than individuals without formal musical training on all auditory spatial and temporal processing measures.

4.2. Performance of individuals with and without formal musical training on auditory spatial processing across different age groups.

This section addresses the second objective of the study and entails the differences in performance among musicians and non-musicians across different age groups on all the behavioural measures.

On similar lines, Kruskal-Wallis test was done to compare the performance difference among the three age groups. The results revealed that musicians separately revealed no effect of age ($p>0.05$) for all the measures, while the same for non-musicians indicated no effect of age ($p>0.05$) for three measures i.e. overall VASI scores, GDT and SSQ. However, the effect of age was observed for ITD ($\chi2= 7.720$, $p<0.05$) and ILD ($\chi2= 13.984$, $p<0.05$), indicating differences in binaural cue processing with age. However, there was no age effect seen on the behavioural measures in musicians. Further Mann-Whitney U test revealed that participants in the age range of 41-50y had significantly lower ($p<0.05$) ITD and ILD thresholds compared to 51-60y and 61-70y. No such difference was seen between age groups 51-60y and 61-70y for ITD threshold but was seen for ILD threshold.

Chapter 5

Discussion

The current study probed to compare the performance difference in musicians and non-musicians with respect to spatial hearing and temporal processing ability. The study also aimed to explore the decline in the spatial performance of listeners with and without musical training on the same behavioural measures as a result of aging. The results of the current study is discussed under the following major headings.

5.1. Comparison of differences in spatial processing between Musicians and Non-musicians on behavioural measures of spatial acuity

and

5.2. Comparison of differences in spatial processing on behavioural measures across different age groups

In this study, an exhaustive audiological evaluation and spatial hearing abilities were conducted in individuals with and without formal musical training. Many factors were measured in the current study and all of them emerged as significantly different between those who had and did not have formal musical training.

5.1. Comparison of differences in spatial processing between Musicians and Non-musicians on behavioural measures of spatial acuity

VAS identification (VASI) test compliments test of localization in making inferences about spatial acuity using identical sources (virtual auditory sources) within the head. Overall VASI score of individuals without musical training was significantly poorer than individuals with musical training. The significantly lower

VASI score in non-musicians reported in the present study is in consensus with the findings of earlier perceptual auditory information of reverberation and its effect in space perception based experiment (Kaplanis & VanVelzen, 2012), wherein they reported that musicians have superior space perception in the tasks mainly in the vertical distance discrimination. Several functional imaging studies have shown differences between musicians and non-musicians while performing motor, auditory, or somatosensory tasks (Elbert et al., 1995; Pantev et al., 1998; Schlaug, 2001). Similarly, structural brain differences between musicians and non-musicians were reported in a few studies defined motor and auditory brain regions (Schlaug et al., 1995a,b; Amunts, 1997; Zatorre et al., 1998; Schlaug, 2001; Schneider et al., 2002; Hutchinson et al., 2003; Lee et al., 2003).

Individuals with musical training had significantly lower thresholds of ITD, ILD, and GDT than non-musicians indicative of better processing of binaural cues. This could be attributed to better intensity and temporal resolution abilities in musicians which is in consonance with results of past studies by Rabin, Amir, Vexler, & Zaltz, 2001; Jain, Mohamed, and Kumar (2014). Musicians had superior performance on perceptual tasks, which do not require reference memory process, suggests that extensive music training may exert a positive effect on timing performance.

As part of the experiment, participants in each group were asked to fill out a brief questionnaire of 17 questions survey from spatial sub-section of the Speech, spatial, and qualities of hearing (SSQ) questionnaire (Gatehouse & Noble, 2004). Complimentary to the differences observed in spatial acuity tests (discussed above) between the two groups of participants, spatial difficulties encountered in daily life were also rated significantly higher by non-musicians relative to those reported by musicians. The emergence of group differences on SSQ is suggestive of perceptual consequences of heightened spatial awareness in musicians. Sluming et al. (2007) demonstrated a strong association between musical ability and visuo-spatial ability for orchestral musicians, who showed significantly increased activation in Broca's area, and visuospatial network relative to non-musicians. On similar lines, musicians also enjoyed perceptual spatial advantage over non-musicians in reverberant environments, especially in vertical plane (Kaplanis & Van Velzen, 2012).

5.2. Comparison of differences in spatial processing on behavioural measures across different age groups

Kruskal-Wallis test was done for musicians separately revealed no effect of age for all the measures, while the same for non-musicians indicated no effect of age for three measures i.e. VASI, GDT and SSQ. However, for ITD and ILD the effect of age was observed, indicating differences in binaural cue processing with age. ITD and ILD being subjective measures and have no supplementary cues for the individuals to rely on. But, this was not the case for VASI stimuli wherein the individuals had other supplementary cues that helped them perform better in the same.

Optimal spatial acuity forms the prerequisite for processing. Spatial acuity along with the properties of the sound relies with the dimensions of the head and external ears. Thus, during development, the cue values associated with any given direction in space will gradually change while these structures are growing. In addition, advancing age leads to changes in the anatomy and physiology of the inner ear including decline in number of outer hair cells, inner hair cells (Wright, Davis, Bredberg, Ulehlova, & Spencer, 1987) and auditory nerve fibres (Makary, Shin, Kujawa, Liberman, & Merchant, 2011), poor blood supply to striavascularis (Schmiedt, 1996), weaker endolymph potential (Schmiedt, 2010), poor inhibitory control of temporal acuity due to depleted neurotransmitters (Caspary, Milbrandt, & Helfert, 1995). Each of these factors or a combination of these factors is likely to show a negative impact on the spatial processing skills of older listeners. Further, non-musicians in the age range of 41-50 had significantly lower ($p<0.05$) ITD and ILD thresholds compared to 51-60 and 61-70. The results of the present study is in consensus with the study done by Abel, Giguere, Consoli, and Papsin (2000), wherein they reported that the spatial acuity declines with age and starts off by 40 years, even when hearing sensitivity is normal.

The benefits of musical training on counteracting age-related decline was not only seen in ITD, ILD, GDT, and SSQ measures, but also extended to VASI test. Age-related spatial processing deficits are common between musicians and non-musicians in all spatial planes. Age-related decline in horizontal plane was noticed for frontal sources (±60° azimuth) by Dobreva et al. (2011). However, reports on right ear superiority of trained musicians for processing of simple auditory stimuli such as melodies or tempo like the one used in the study is documented in literature (Bever & Chiarello, 2009).

From the current findings, we speculate that, the protocol used in the present study can be clinically effective and time efficient.

Chapter 6

Summary and Conclusions

The current study investigated the spatial processing, binaural processing and temporal resolution abilities in individuals with and without formal musical training using a series of behavioural measures. The spatial, binaural and temporal abilities of individuals with formal musical training were compared to individuals with no formal musical training to measure the extent of spatial plasticity on behavioural measures. Further, the present study highlights the benefit of musical training on age-related decline of auditory processing.

The study was conducted on 36 musicians and 36 non-musicians who were divided into three groups based on their age. Group 1, 2, and 3 comprised of participants in the age range of 41-50 years, 51-60 years and 61-70 years respectively. Musicians considered in the study had formal musical training for at least 5 years and practiced music for at least 9 hours per week. All the participants included in the study had hearing thresholds below or equal to 25 dB hearing level (HL) between 125 Hz and 8 kHz. The behavioural tests included in the study were test of spatial acuity using virtual sources, test of binaural processing skills (including interaural time and level differences- ITD and ILD), test of temporal resolution ability (GDT) and subjective ratings (Spatial sub-part of SSQ questionnaire). All the tests were done using 250 ms white noise bursts. Test of spatial acuity using virtual sources comprised of randomly presented eight virtual stimuli. Overall virtual acoustic space identification (VASI) scores was obtained. ITD, ILD and GDT thresholds were measured using psychoacoustics toolbox implemented in Matlab environment. Apart from this spatial sub-part of SSQ was used to measure subjective ratings.

The results showed that individuals with formal musical training performed better than non-musicians on all the behavioural measures. Although a trend of steady decline in psychoacoustic abilities with advancing age was seen for both musicians and non-musicians in the study, results showed no statistical significance in both the sub-groups except for ITD and ILD thresholds in non-musicians. The current study finding showed non-musicians in 41-50y age group had significantly better ILD sensitivity than other two groups (51-60y and 61-70y). In summary, the binaural processing (ITD & ILD thresholds) deficits seen with advancing age were not observed in musicians, indicative of positive outcomes of musical training.

Implications of the Study

- The results of the current study on auditory spatial perception in musicians and compare of the same with non-musicians highlighted a number of interesting and important aspects of auditory space perception. The results of the study also showed the efficacy of musical training in remediating spatial deficits using multiple behavioural measures.
- Training in music can be used as a potential therapeutic tool to improve auditory processing skills in learning disabled, language impaired, dyslexic, hearing impaired and other individuals, for whom the auditory processing is compromised.
- Overall, the findings suggest that VAS Identification task contains critical information that serve older individual’s as a cue to identify and the human auditory system is capable of processing them. Musicians show superior space perception in both tasks, especially in vertical distance discrimination, a behaviour similar to blind individuals. Further, following the results of spatial sub-section of SSQ, it could be argued that spatial difficulties encountered in

daily life were also significantly higher for non-musicians relative to those for musicians.

- Based on the findings, of this study provides enough evidence that musical training creates an accurate auditory representation of the space, and self-locate within that space.
- Current findings, integrated with numerous previous studies on musicians, suggest that musical training can prevent or delay deterioration in certain auditory processing abilities. The findings of the study creates promising new avenues for research in field of rehabilitative audiology, with wide spread applicability of using music as toughening agent to counteract ageing effects. Clearly, more research in future is warranted to disentangle the neural correlates of auditory processing underlying age-related changes in musicians.

Future Directions

- All the behavioural measures adopted in the current study were conducted using noise as stimuli. Taking cue from this, future research can be put-forth in the direction of using more ecologically valid stimuli like speech in understanding the effects of musical training.
- Traditional waveform analyses of identifying speech ABR peak latency and amplitude can also be incorporated along with the behavioural measures to measure any differences in the waveform between musicians and non-musicians. Thus, speech ABR can serve as a sensitive measure in identifying any subtle differences between the groups. Spatiotemporal analyses must be implied in addition to traditional waveform analyses to track subtle changes induced by musical training, which might not be readily apparent in conventional analyses.

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