ASSESSMENT OF SPATIAL HEARING ABILITIES IN BHARATANATYAM DANCERS

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ALL INDIA INSTITUTE OF SPEECH AND HEARING

MANASAGANGOTHRI, MYSURU - 570 006

SEPTEMBER, 2023

CERTIFICATE

This is to certify that this dissertation entitled **'Assessment of Spatial Hearing Abilities in Bharatanatyam Dancers'** is a bonafide work submitted in part fulfilment for degree of Master of Science (Audiology) of the student Registration Number: P01II21S0083. 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
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CERTIFICATE

This is to certify that this dissertation entitled **'Assessment of Spatial Hearing Abilities in Bharatanatyam Dancers'** 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 **'Assessment of Spatial Hearing Abilities in Bharatanatyam Dancers'** 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,
September, 2023

Registration No. P01II21S0083

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Abstract

Background: *Bharatanatyam is an art form that makes use of body motions that are choreographed and timed to Carnatic music. Bharatanatyam dance training has a significant impact on coding of sound signals in the auditory system. Spatial hearing indicates the auditory system's ability to comprehend or relate sounds that arrive at the head via various spatial pathways. Tests of spatial acuity includes Virtual auditory space identification (VASI), Inter-aural level difference (ILD) & Inter-aural time difference (ITD).*

Aim: *The present study aims to evaluate the auditory spatial abilities in Bharatanatyam dancers using Virtual auditory space identification (VASI), Inter-aural level difference (ILD) & Inter-aural time difference (ITD).*

Method: *Ninety-two females belonging to an age range of 18 to 25 years were grouped into three groups, group I of control participants (individuals with no formal training of dance and music) (N=30), group II consisted of formally trained Bharatanatyam dancers (N=32), and group III consisted of formally trained vocal musicians (N=30). Tests of spatial acuity (VASI, ILD and ITD) was performed.*

Results: *The results of Kruskal Wallis test revealed significant difference in VASI scores, ILD threshold and ITD thresholds between Bharatanatyam Dancers, Vocal musicians and control group. There was significant association between VASI scores and ILD & ITD thresholds in both Bharatanatyam dancers and vocal musicians.*

Conclusion: *Bharatanatyam dancers performed superior to both formally trained musicians and control group in all the spatial acuity tests. Thus, it can be concluded that Bharatanatyam dance training has a significant impact on coding of sound signals in the auditory system. The results obtained from the current study suggests that the VASI test is more sensitive in measuring differences in auditory spatial processing.*

Key words: *Spatial Hearing, ILD, ITD, VASI, Bharatanatyam dancers, Binaural cues*

Chapter 1

Introduction

Spatial hearing indicates the auditory system's ability to comprehend or relate sounds that arrive at the head via various spatial pathways. The complex auditory system processes the detection and tracking of an auditory object's position in three dimensions. Additionally, the auditory system can direct attention towards or away from a sound source using spatial processing of acoustic stimuli (Culling & Akeroyd, 2010).

The spatial resolution of the auditory system is two orders of magnitude lower than that of the visual domain, which is limited to the frontal plane (Grantham, 1995). Therefore, the auditory system's capacity to locate sound sources in all directions facilitates decision-making, task performance, and identification (Smith et al., 2012). In order to perceive speech signals in noise and reverberating environment, the spatial hearing plays a crucial role (Takahashi, 2009). It also aids in the perception of music and makes it easier to exchange ideas with a communication partner (Byrne & Noble, 1998).

Binaural hearing, which is supplemented by spatial hearing, enables individuals to contrast the signals in each ear. The inter-aural level difference (ILD), which is essential for localizing high-frequency noises beyond 1.5 kHz and can reach a maximum of 20 dB at 6 kHz, reflects these. When sound waves are attenuated by the skull, this results in a difference in intensity between the two ears (Grantham, 1995). Interaural time differences (ITD), which are the times at which signals arrive at each of the two ears, serve as a secondary cue for the spatial localization of sounds. The time difference between the two ears signal arrivals, or inter-aural time differences (ITD), is the second cue for localizing sounds in space. It is a key cue for locating low-frequency sounds up to 1.5 kHz, (Brughera, et al., 2013). The ILD and ITD cues, which are essential to spatial hearing, serve as the foundation for binaural processing.

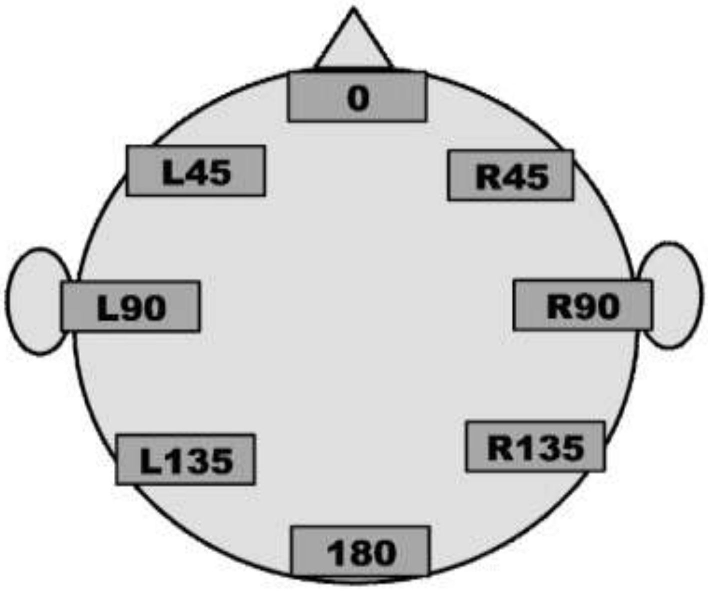
These binaural cues ITD and ILD codes are primarily utilized for right-left localization, while spectral cues are extensively used to explain front-back localization (Blauert, 1997; Hoffman et al., 1998). The concrete cue of ILD for a sine wave performs best at high frequencies, whereas the cue of ITD performs best at low frequencies. The concept is known as the ‘duplex hypothesis’, in which the ITD at low frequencies and the ILD at high frequencies are used to localize sound (Rayleigh, 1907). It is well known that azimuth and elevation are primarily determined by binaural and monaural inputs, respectively. It illustrates how the pinna or outer ear functions as an audio cue. Some frequencies are amplified by their resonant chambers and shape, whereas interference effects attenuate other frequencies. Additionally, it has a directionally dependent frequency response.

For the perception of elevation, front-back distinctions, and monaural localization, the spectral cues, also known as pinna cues and monaural spectral cues, introduced by the pinna at high frequencies are crucial (Midlle et al., 1974; Blauert, 1997; Middlebrooks, 1997) additionally, the extra-cranialization of sound sources is facilitated by these pinna cues (Plenge, 1974; Blauert, 1997). Vertical localization is made possible by low-frequency signals associated with head diffraction and torso reflections (below around 3000 Hz) (Algazi et al., 2001: Gardner, 1973). Pinna reflects sounds from the front more effectively than it does with sounds from above, resulting in a notch that is more noticeable for sound sources from the front than from the top. Because the length of the route difference varies with the elevation angle, the frequency of the notch also shifts with elevation. Despite differences in opinion regarding the characteristics that are perceptually significant, it is widely accepted that the pinna serves as the primary indicator for elevation.

Virtual auditory space identification (VASI) is a special acuity test that employs illusionary specific precepts within the head in a closed field. In this test, eight different spatial locations within the head are simulated using virtual auditory space (VAS) stimuli: mid-line front (0° azimuth), mid-line back (180° azimuth), 45° toward the right ear (R45), 90° toward the right ear (R90), 135° toward the right ear (R135), 45° toward the left ear (L45), and 90° toward the right ear (L135) (Nisha et al., 2016). The stimulus delivery and response acquisition are controlled by a graphical user interface built with the paradigm software that powers the VASI. It is represented in the figure 1.1. A calibrated headphone is used to play each virtual acoustic stimulus ten times (total = 8*10 = 80 times) at a presentation level of 65 dB SPL.

Figure 1.1.

Virtual acoustic space identification (VASI) test's user interface.



The VASI test is an effective tool for identifying spatial accuracy deficits. The test has a number of benefits since it involves (1) utilization of spectral cues (which ITD and ILD tests do not), (2) is portable (as opposed to measurements based on loudspeakers), and is affordable (Nisha et al., 2022). Sanjana et al., (2022) investigated the effects of abacus training on psychoacoustic metrics in children using a variety of psychoacoustic tests, including interaural time difference (ITD), inter-aural level difference (ILD), and virtual auditory space identification (VASI), and they discovered convincing evidence that abacus instruction affected the auditory spatial domain of school going children.

Bharatanatyam is a synchronised art form that originated in Tamil Nadu in South India in the fourth century. This traditional form of dancing makes use of body motions that are choreographed and timed to Carnatic music. It illustrates stories or events from Hindu epics using synchronised and stylized motions as well as paralinguistic components including gestures and facial expressions (Banerjee, 2013; The Editors of Encyclopedia Britannica, 2018). Numerous studies have examined both neuroplasticity and the therapeutic advantages of Bharatanatyam. Bharatanatyam-based dance therapy improved balance, cardio-respiratory fitness, and lower limb muscle strength in adolescents and kids with Down syndrome, according to a study by Parab et al. (2019).

In 2013, Swathi and Sathish evaluated the Cervical Vestibular Evoked Myogenic Potential (C-VEMP) of dancers. They found that, compared to the control group of age-matched females who had never taken dancing classes, the P13 and N23 peaks in the CVEMP waveform had an earlier latency and greater amplitude. Sinha et al. (2013) revealed contradicting results, finding that the cervical VEMP and the ocular

VEMP's P13eN23 complex and N10eP14 complex did not significantly differ from those of non-dancers in either amplitude or latency, respectively.

According to Joseph et al. (2019), Bharatanatyam dancers who had higher contralateral suppression of otoacoustic emissions (OAE) compared to non-dancers had improved efferent auditory pathway functioning. In addition to receiving physical training, they are also receiving musical instruction (The Editors of Encyclopedia Britannica, 2018), which may cause their auditory nerve system to become more malleable. Long-term, intensive auditory and motor training may speed up the rate at which auditory stimuli and motor commands are processed in succession with constantly changing rhythm. They must have a lightning-quick response to auditory cues and precise motor planning in order to master this art. Prakash et al. (2021) revealed that Bharatanatyam dancers had better auditory working memory, which might be interpreted as proof of neuroplastic changes brought about in the auditory and motor cortex as a result of intensive auditory stimulation.

Intense musical training for years together has been known to fine tune musicians' auditory skills (Gaser et al., 2003; Munte et al., 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 et al., 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 inmusicians. A study was conducted by Mohamdkhani et al. (2010) and they concluded saying that the musicians had rapid temporal processing ability as they showed lower threshold in the Gap in Nosie test. The outcome of the study was attributed to the effect of musical training on central auditory processing. In another study conducted by Thomas et al., (2011) wherein he investigated temporal resolution abilities in musicians using GDT and TMTF, the results revealed that the musicians had better temporal resolution abilities whichbecame 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 betterperformance in musicians.

1.1. Need for the study

In additional to fine motor skills, performing a Bharatanatyam dance with precise rhythm and coordination requires fine auditory skills and faster coding of acoustic signals in different parts of the auditory pathway. Undergoing long term training could have an impact on the auditory neuroplasticity. A handful of studies have been conducted in documenting the auditory abilities in these dancers which have yielded an enhanced coding/processing of auditory skills, Prakash et al., (2022). However, no research has attempted to investigate the auditory abilities and spatial hearing of formally trained dancers. Therefore, this population's auditory and spatial perception abilities must be investigated.

1.2. Aim and objectives

The present study aims to evaluate the auditory spatial abilities in Bharatanatyam dancers using Virtual auditory space identification (VASI), Inter-aural level difference (ILD) & Inter-aural time difference (ITD).

Following were the objectives of the study;

1. To compare the VASI scores obtained by control group, formally trained dancers and Musicians.
2. To compare the ILD scores obtained by control group, formally trained dancers and Musicians.
3. To compare the ITD scores obtained by control group, formally trained dancers and Musicians.
4. To assess the relationship between VASI scores and ILD & ITD scores in formally trained dancers.
5. To assess the relationship between VASI scores and ILD & ITD scores in formally trained musicians.

1.5. Null Hypothesis

1. There is no significant difference in the VASI scores obtained by control group, formally trained dancers and Musicians.
2. There is no significant difference in the ILD scores obtained by control group, formally trained dancers and Musicians.
3. There is no significant difference in the ITD scores obtained by control group, formally trained dancers and Musicians.
4. There is no significant relationship between VASI scores and ILD & ITD scores in formally trained dancers.
5. There is no significant relationship between VASI scores and ILD & ITD scores in formally trained musicians.

Chapter 2

Review of Literature

Spatial hearing is a complex process that involves the auditory system's ability to interpret sounds arriving from different directions (Culling & Akeroyd, 2010). The brain uses a variety of cues to determine the location of a sound source, including the inter-aural time differences (ITD) and level differences (ILD) between the two ears (Grantham, 1995). These cues help the brain to understand the spatial location of a sound within a three-dimensional environment. Blauert (1997) further highlighted that spatial audition is not only limited to the physical location of the sound source, but also involves various interactions between different variables and acoustic spaces. For instance, the reverberation and reflection of sound waves within a room can significantly impact the perceived spatial qualities of a sound. It is also worth noting that spatial hearing is not just limited to the ability to focus on or away from a sound source. According to a study, listeners can also use spatial hearing to describe the characteristics of the listening space (Grantham, 1995). This includes factors such as the size of the room, the materials used in construction, and the ambient noise levels.

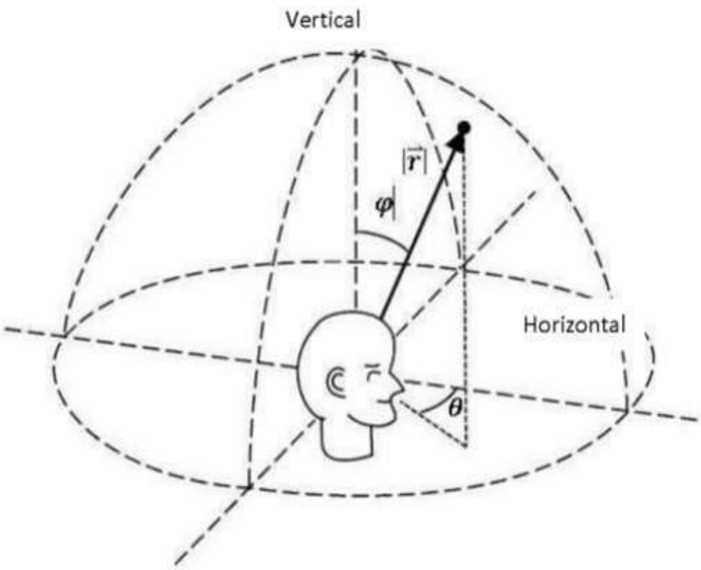
In presence of competing acoustic signals, such as noisy or reverberant environments, spatial hearing becomes a crucial prerequisite for optimal performance (Blauert, 1997). The ILD and ITD cues, along with other spatial cues, allow the brain to separate sounds and focus on speech or other important auditory information. Therefore, understanding the intricacies of spatial hearing is essential for developing effective auditory processing strategies in challenging situations (Grantham, 1995). Research studies on spatial hearing have delved into different aspects such as acoustical basis, physiological basis, perception of spatial signals and factors influencing stimulus-related, task-related, and subject-related aspects of spatial processing. (Wightman & Kistler, 1997). Additionally, these studies have also focused on understanding the differences in spatial perception between individuals with and without professional musical training, which is a crucial element in comprehending the complexities of spatial hearing. The following areas of literature were reviewed while taking these concerns into consideration in relation to the study's goals and objectives.

2.1. Spatial hearing and related phenomena

To better understand their surroundings, humans have evolved a specialized form of spatial hearing. The auditory system must first examine the spatial layout of the sound source in three dimensions, then tag the sources to prevent confusion, and last, dismiss the unimportant ones in order to perceive spatial information accurately (Blauert, 1997). There are various ways to understand how sound sources are perceived in space. The direction and distance of the sound are mentioned in relation to the location of the sound source in the actual space. The location of the sound is inferred from either a single source or several sources. When there are numerous sources, one of them may be coherent (sound events take place at the same time) or incoherent (sound events take place at various periods in time) (Blauert, 1997). The reference framework for where sound is located in physical space is shown in Figure 2.1.

Figure 2.1.

The framework of reference for the location of sound in physical space.



Source location in space is defined with azimuth (θ), elevation (φ), and distance alongthe horizontal and vertical planes (adapted from Blauert, 1997).

Another angle on direction perception is examined by considering the horizontal and vertical reference planes in relation to the sound location. The horizontal plane is defined as the left or right spatial fields extending on each side of the medial plane. The vertical plane is the axis for localizing sounds along the medial plane, whether they are located above or below the listener. The perception of sound in the horizontal or vertical plane is typically influenced by the following cues: Inter-aural time difference (ITD), Inter-aural level difference (ILD), Spectral cues (pinna and torso cues), Direct to reverberation ratio (DRR), Sound intensity level, Dynamic cues (head movement cues), Familiarity of the sound source, Visual and other non-auditory cues (Blauert, 1997; Xie, 2013). Among these cues, ITD and ILD codes for azimuth, spectral cues aid in elevation, whereas the combination of DRR and sound level aids in distant perception

(Grantham, 1995). The first five cues relate to acoustic-based cues while the last three relate to non-auditory cues.

2.1.1. Acoustic pathway

Considering the positions of sound sources in human listeners, the acoustic signals that reach the two ears are modified. Spatial hearing cues are the components of signals that can be used to compute locations and are roughly classified into two groups based on the physical characteristics of the listener.

2.1.1.1. Spatial sampling of the sound field. The two ears that are thought of as receptors are situated at two distinct points in space. Natural phase and timing discrepancies are produced by the geographic separation between the sensors. The ITD is the outcome of the receptors sampling and collecting sounds normally at two physical places in acoustic space (Zhong, 2015).

2.1.1.2. Diffraction of sound by the human body. The wavelengths of the sound waves could be diffracted by things whose dimensions are similar to those of the objects. High-frequency sounds (2-3 kHz) can be diffracted by both the head and the torso in addition to the mid-frequency sounds (1-1.5 kHz) that can be diffracted by the torso (Zhong, 2015). The pinnae can diffract even higher frequency sounds (4-17 kHz) (Shaw, 1997). These effects cue for monaural localization, ILD, and head-related transfer functions (HRTF).

2.1.1.3. Inter-aural time difference. Since there is a relatively broad head between the two ears, the paths taken by sound to reach each differ, resulting in a time discrepancy between the ears known as the interaural time difference. Sound will travel farther to the ear far from the source than to the ear close to it. As a result, there is a delay between the far and near ears. The head size and sound speed influence the interaural time difference. The interaural time difference is zero for sounds that are incident from the front and reaches its maximum for noises that are incident from 900 degrees behind (Zhong, 2015). The ITDs threshold in humans is thought to range from 10 to 670 s, according to psychoacoustical research that has been published in the literature (Blauert, 1997; Brughera et al., 2013; Klumpp & Eady, 1956). ITDs vary regularly with stimulus duration (Hafter & Maio, 1977; Tobias & Stanley, 1959); level (Nicolas et al., 2011); and source azimuth (Kuhn et al., 1977). With regard to the fact that low frequencies up to 1500 Hz have wavelengths longer than the path around the head, which is why they bend around the head, this time difference is a key cue for localizing these sounds. Beyond 1 kHz, the ITDs rise sharply, making it impossible for listeners to localize sounds using ITDs after 1.4 kHz (Brughera et al., 2013).

2.1.1.4. Inter-aural level difference. The Interaural Level Difference (ILD) is an important factor in determining how sound is perceived by the human ear. As mentioned earlier, the wavelength of high and low frequency components of sound plays a crucial role in the intensity reduction experienced by the signal when it reaches the far ear. The ILD is the difference in level between the two ears and can also be influenced by the wavelength and intensity of the stimulus (Hafter et al., 1977; Koehnke et al., 1995). Additionally, the ILDs are also dependent on various other factors such as the location, inclination, and orientation of the sound source (Brungart & Rabinowitz, 1999).

2.1.1.5. Spectral cues. While the ITD and ILD code for horizontal localization, pinna-based spectral cues play a significant role in vertical localization (Grantham, 1995). The reflections and resonances in the pinna before the sound enters the ear canal enable it. At specific frequencies, depending on the source elevation in relation to the head, spectral peaks and notches are produced due to these reflections and resonances. The wavelength of the sound is only similar to the size of the pinna in this high-frequency area, allowing for essential reflections and resonances, and as a result, the cues to localization in the mid-sagittal vertical plane are all over 5000 Hz (Blauert, 1997).

Sound reflections are known as pinna echoes; a sound from below will produce an echo that is significantly later (by about 300 microseconds) than a sound from above (by about 100 microseconds). The outer ear's ridges and bumps appear to reflect sounds that enter the ear (Tollin, 2004). Vertical localization is made possible by the delays between the direct path and the reflected path (Bear et al., 1996). Two more spectral signals are typically inferred in vertical-plane localization in addition to these two. These include the interaural pinna disparity cue and the torso's function. According to a study, the reflections from the torso typically contain significant spectral indications between 2-3 kHz (Grantham, 1995). For frequencies above 8-10 kHz, the interaural pinna disparity cue offers helpful information (Butler et al., 1990; Middlebrooks et al., 1989; Searle et al., 1976).

Each pinna's contribution to the perception of vertical angle was examined by Morimoto (2001). The vertical angle's localization in five planes perpendicular to the median plane was determined through tests. The pinna cavities of one or both ears were blocked during the localization tests. The findings demonstrated that both the pinna cavities of the near and far ears contribute to the perception of the vertical angle of the sound source in any plane, including the median plane. The near ear's contribution rises when a sound source moves laterally away from the median plane, whereas the far ear's contribution falls. The far ear no longer contributes noticeably to determining vertical angle for sagittal planes at azimuths larger than 60 degrees from midline (Morimoto, 2001).

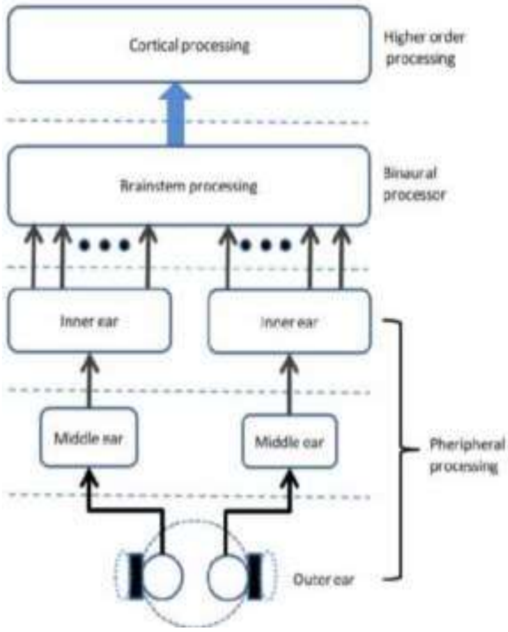
2.1.2. Auditory pathway

The human hearing has a number of stages in the auditory spatial perception. The ventral and dorsal streams, commonly known as the "what" and "where" pathways, involved in spatial perception are modified by events throughout life and evolve into a matured system (Carlile, 2014). The outer-ear components, which have a complicated, convoluted shape, process the sound input first. When outer ear structures interact with incoming sound, a complex pattern of sound resonance and diffractions occurs. This is exacerbated by the pinnae's anatomic position. The physical distance between the two pinnae creates changes in the arrival time and intensity of sound signals reaching the back ear (compared to the farther ear), resulting in ITD and ILD (Carlile et al., 1994). The outer-ear structures develop significantly with age, particularly throughout early childhood, until the age of 7 to 8 years (Wunderlich et al., 2006).

The development and functional maturation of ear structures mirrors the development and functional maturation of auditory spatial perception, which is primarily described as a function of the outer-ear structures. The basic internal representations of auditory spatial awareness form at 6 months of age and are gradually refined until 7 to 8 years of age. Because of the alterations in head size, the growth becomes protracted. The peripheral developmental processes are accounted for by all of these alterations in outer-ear structures. Similarly, the development of higher centers, such as the brainstem and cortices, occurs by late childhood, around the age of 11 years (Moore, 2002). The coordinated development of these anatomical structures, in turn, contributes to changes in spatial acuity that continue to mature until the age of 12. This is represented in Figure 2.2.

Figure 2.2.

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



ILD is an essential component in determining the localization of sounds in space. ILDs are calculated based on the difference in sound pressure level between the ears of the listener. These differences are shaped by the head, torso, and pinnae, and can be measured using HRTFs (Algazi et al., 2001; Blauert et al., 1997; Wightman & Kistler, 1989). The HRTFs are unique to each individual due to anatomical variations, resulting in different values for different people. The transformed sounds then travel through the middle ear, efficiently transmitting the sound signals to the brain for further processing. After sound energy is transformed into mechanical energy, the middle ear sends it to the inner ear. The overall resonance peak of the ear shifts from 3 kHz of the ear canal to 4 kHz as a result of the combined action of the middle ear and ear canal (Blauert et al., 1997). Sound impulses are converted by the inner ear and sent to the brain pathways. With very little involvement in spatial processing, the peripheral only does signal filtering and spectrum decomposition.

The brainstem is where the spatial breakdown of the stimuli begins. In the brainstem, the various auditory stimuli are processed via separate cerebral pathways (Young & Davis, 2002). The lowest level of the brainstem, the lateral superior olive, contains ILD-sensitive neurons. On the other hand, it has been discovered that the medial superior olive neurons are responsive to ITD (Goldberg & Brown, 1969; Yin & Chan, 1990). The dorsal division of the cochlear nucleus (DCN) processes the spectrum cues in spatial hearing (HRTFs). Type IV neurons that are responsive to the spectral notches in white band signals are also present in this region (Grothe et al., 2010). The neuronal network transfers directionally dependent spectral cues from type IV DCN neurons to type O neurons in the inferior colliculus (Davis et al., 2003). Additionally, the central cortical systems produce a representation of the object's location based on these processed spatial cues. The superior colliculus (SC) has at least two distinct modalities of cortical representation, while the auditory cortex (AC) has a dispersed representation (Middlebrooks, 2015). When noises are given in a small area of space, the neurons in the SC respond most strongly (Middlebrooks, 2015). Both spike counts and spike timing are used by AC neurons to transfer information (Furukawa & Middlebrooks, 2002; Mickey & Middlebrooks, 2003).

2.2. Behavioural/psychoacoustical methods employed to investigate spatial processing

The studies on spatial acuity with real sources use loudspeakers to simulate real-world listening situations where all spatial cues for sound perception, such as ITD, ILD, pinna, and head effects, are intact. A popular technique for identifying sources is to use real sources; the experimental details can vary, such as whether the loudspeakers are visible (Yost & Zhong, 2016) or hidden behind a curtain (Freigang et al., 2014) the response can be verbally reporting the direction of the loudspeaker which delivers the sound (Neher et al., 2011) or giving the direction perse by pointing the hear toward the sound (Best et al., 2011).

An additional technique that is widely used in audio engineering is the employment of ILD. ILD is used in conjunction with the HRTFs to create a synthetic directional audio experience. The ILD is the difference in sound level reaching each ear and is caused by the head's shadowing effect. This effect is calculated using the HRTFs, which capture the way sounds travel from a specific point in space to the entrance of the ear canals (Wightman & Kistler, 1989). Together, ILD, ITD and HRTFs allow virtual acoustics to emulate a sound environment that is as close to reality as possible. It is the level difference between the sound reaching the two ears and is crucial in determining the directionality of the sound. The use of ILD in the modified signals presented through headphones helps in creating an accurate and realistic experience for the listener. This is achieved by replicating the natural ILD that occurs in free-field environments. Therefore, the virtual acoustic space created through ILD is no different than the experience of hearing the sound in an actual free-field environment.

2.3. Spatial hearing in listeners with and without Bharatanatyam training

Bharatanatyam is a synchronized art form which has the origin in Tamil Nadu in South India in the fourth century. This traditional form of dancing makes use of body motions that are choreographed and timed to Carnatic music. It illustrates a set of different stories from Hinduism using synchronized and stylized motions as well as paralinguistic components including gestures and facial expressions (Banerjee, 2013; The Editors of Encyclopedia Britannica, 2018). Numerous research works have examined both neuroplasticity and the therapeutic advantages of Bharatanatyam. Bharatanatyam-based dance therapy improved balance, cardio-respiratory fitness, and lower limb muscle strength in adolescents and kids with Down syndrome (Parab et al., 2019). Swathi and Sathish (2013) evaluated the Cervical Vestibular Evoked Myogenic Potential (C-VEMP) of dancers. It was found that, compared to the female participants in the control group who had never taken dancing classes, the latency of P13 and N23 peaks were earlier, and amplitude was greater. Sinha et al. (2013) revealed contradicting results, finding that the cervical VEMP and the ocular VEMP's P13eN23 complex and N10eP14 complex did not significantly differ in amplitude and latency in non- dancers compared to dancers.

Joseph et al. (2019) reported that Bharatanatyam dancers had higher degree of suppression which was observed using contralateral suppression of otoacoustic emissions (OAE). It is a suggestive marker of an improved efferent auditory pathway functioning. In addition to receiving physical training, they are also receiving musical instruction (The Editors of Encyclopedia Britannica, 2018), which may cause their auditory nerve system to become more malleable. Long-term, intensive auditory and motor training may speed up the rate at which auditory stimuli and motor commands are processed in succession with constantly changing rhythm. They must have a lightning-quick response to auditory cues and precise motor planning in order to master this art. A study by Prakash et al. (2022) revealed that Bharatanatyam dancers had improved auditory working memory, which might be interpreted as proof of change in neuroplasticity happens at the auditory and motor cortex because of the intensive auditory stimulation. Only a few studies have attempted to examine dancers' auditory skills and spatial hearing. Investigating this population's auditory perceptual and spatial perception abilities is therefore necessary.

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 et al., 2003; Munte et al., 2003). Research studies have shown that such training seems to have a significant impact on the development of auditory skills in children. Children who receive musical training at an early age have been found to be more sensitive to sound changes, which is essential for speech and language development. The findings have also reported that musical training benefits auditory training not only in the musical domain but also in the processing of speech stimuli (Musacchia et al., 2004; Wong et al., 2007). Therefore, it can be suggested that introducing children to music at a young age can aid in their auditory development and provide a foundation for their future linguistic abilities.

Functional and structural differences exist in the auditory processing abilities between musicians and non-musicians; thus, musical training influences temporal processing. Rammsayer and Altenmuller (2006) reported that musicians had superior temporal discrimination abilities than non-musicians. They reported that temporal information processing is more accurate in musicians. A study was conducted by Mohamdkhani et al., (2010) and they concluded saying that 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 whichbecame 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.

2.5. Factors affecting spatial hearing

The process of spatial hearing entails the use of two sets of cues that the listener relies upon for its successful completion. The first set of cues used are acoustic cues, while the second set of cues are related to various factors. These factors include stimulus-related factors such as duration, frequency, and type of stimulus (Grantham, 1995). Additionally, task-related factors such as uni- v/s multi-sensory processing, the role of distractors, types of learning, and feedbacks are also significant. Finally, subject-related factors like motivation, memory, and attention play a crucial role in spatial hearing (Blauert, 1997).

2.6. Factors affecting spatial localization

2.6.1. Stimulus related factors.

The impact of stimulus type on source localization was examined and they showed that localization errors were highest for the wrapped (44.5°) stimuli using 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. They also concluded that broadband (32.9°) stimuli were the easiest to localize, while band restricted (39.8°) stimuli had lower localization errors (Majdak et al., 2013). Spatial processing can also be influenced by the frequency of the stimulus band. The type and quantity of spatial cues used depend on the stimulus band frequency such as 1-16 kHz (Carlile et al.,1997), and/or 1-3 kHz (Lewald & Ehrenstein, 1998). Sound localization is affected by the acoustic characteristics of the stimulus, such as intensity and duration (Hofman & van Opstal, 1998; Macpherson & Middlebrooks, 2000; Vliegen & van Opstal, 2004). In a study it was discovered that participants found it harder to localize clicks that were presented at high levels (86 dB SPL) than clicks that were presented at intermediate levels (74-86 dB SPL), which were harder to localize than lower levels (68-80 dB SPL) (Macpherson & Middlebrooks, 2000).

2.6.2. Procedure related factors.

It is widely accepted that one of the main contributors to the severity of spatial errors is the type of replies utilised in the task. There are four main categories of responses for sound localization (Comalli & Altshuler, 1975): kinaesthetic (using a laser, for example), visual (looking at a map or numbers on a screen, for example), auditory (using a loudspeaker on a boom), and verbal (calculating the angle). In a comparison of several pointing methods, Carlile et al. (1997) found that head (nose) pointing was more precise than verbal estimations or the use of a pen with a tablet. Majdak et al. (2010) examined nose and hand pointing for horizontal and vertical localization tasks, they discovered identical localization performance for both techniques.

Blauert et al., (2000) concluded from meta-analyses of localization studies that methods that involve pointing towards the sound source or verbally indicating its location are typically more precise than system-specific responses like using a display screen, drawings on paper, etc. This was accurate for inexperienced listeners who had little to no prior knowledge of how to use the particular pointing method.

2.6.3. 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 et al., 2007). The shift in sound location judgments was modulated by handedness of the listener and also shift was observed for left-handed listeners ie., rightward and a vice-versa for right-handed listeners ie., leftward (Ocklenburg et al., 2010).

Other factors such as listener's eye position during the localization task can also affect spatial perception (Razavi et al., 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 inperception of object location (Goossens & Van Opstal, 1999; Vliegen et al., 2004).

Chapter 3

Methods

3.1. Selection of participants

Ninety-two female participants belonging to an age range of 18 to 25 years were enlisted for the study. The participants were grouped into 3. Group I which consisted of controls (N=30), group II (N=32) which consisted of dancers and group III (N=30) which consisted of formally trained Vocal musicians. Informed consent was obtained which specified the willingness of participants prior to initiation of the test procedures. All the participants who participated in the study had normal hearing sensitivity. Individuals who have undergone formal Bharatanatyam training for a minimum of five years and who are currently undergoing regular practice was considered in group II of the experimental group. Individuals who have been practicing vocal music for at least five years and now receive regular training or practice was included in group III of the experimental group.

The control group comprised of individuals who have not participated in any theatrical productions or cultural events, nor had they received any formal training in any dance styles. It was established through a structured interview. All participants had a common formal education background. Subjects recruited in the control group had no or minimal experience with sports, athletics, or physical training.

3.1.1. Exclusion criteria

People with any of the following conditions were not taken into consideration for the study:

- History of current presence of middle ear infections
- Any neurological or psychological abnormalities

- Any other conditions, such as tinnitus or hyperacusis
- If they often smoke and/or consume alcohol
- If they are taking any medications for systemic disorders.
- If they often wear any kind of ear protection
- If they have a habitual usage of earphones/ personal listening devices for more than two hours each day or have a listening habit of more than 50% volume levels.

The study eliminated anyone who has had specialized training in any motor, athletics, abacus, chess, etc.

3.2. Test environment

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

3.2.1. Preliminary evaluations.

A complete case history was obtained from each participant as a first step to rule out any pathological abnormalities of the auditory system and to learn more about their work environment and past work. Using a dual channel diagnostic audiometer in a sound-treated room, pure tone audiometry for octave frequencies ranging from 250 to 8000 Hz was performed in accordance with the modified Hughson and Westlake protocol described by Carhart and Jerger in 1959. The requirements of 25 dB HL pure tone average of 500 Hz, 1000 Hz, 2000 Hz, and 4000 Hz were taken into consideration in order to rule out the occurrence of any peripheral hearing loss in the participants. Speech Recognition Thresholds (SRT) were obtained using a Kannada paired-word list developed at the department of Audiology, AIISH, Mysore. Speech Identification Scores (SIS) was determined using a Phonemically Balanced Kannada Word Test

(Yathiraj & Vijayalakshmi, 2005). Immittance evaluation, which involved tympanometry utilizing a 226 Hz probe tone and acoustic reflex testing at 500 Hz, 1000 Hz, 2000 Hz, and 4000 Hz using a GSI-Tympstar middle ear analyzer (American National Standard Institute S3.39, R 1996) was performed to rule out the presence of any middle ear dysfunction. OAE measurements were made using an Otodynamics ILO V6 Echoport system which was calibrated. DPOAEs (Distortion product otoacoustic emissions) for two tones, f1 and f2 (primaries), with intensities of 65 dB SPL and 55 dB SPL (L1 and L2, respectively), was acquired. OAEs were considered pass if there is a +6 dB SNR at three consecutive frequencies. Participants who met the mentioned selection requirements were considered for further test procedures. Additionally, the stimuli for the assessments of binaural interaction (ILD & ITD) were presented through a calibrated headphone using a laptop running MATLAB (The Mathwork, Natick, USA).

3.3. Test Procedure

Listeners with and without formal dance and music training were subjected to a comprehensive behavioral evaluation of their spatial processing abilities as part of the testing. A virtual source identification test (VAS) and a binaural interaction test (thresholds of ITD and ILD) were among the behavioral tests. Both groups of participants underwent the behavioral tests of spatial acuity. Wideband noise (WBN) with a bandwidth of 250 milliseconds and an overall level of 80 dB SPL was used for all behavioral tests in the study. WBNs contain all of the acoustic cues needed to accurately perceive a location (Carlie, 1996; Kulkarni et al., 1998). Therefore, auditory spatial abilities were evaluated using WBNs.

3.3.1. Test of binaural processing [Inter-aural Latency Difference (ILD) and Inter-aural Time Difference (ITD)].

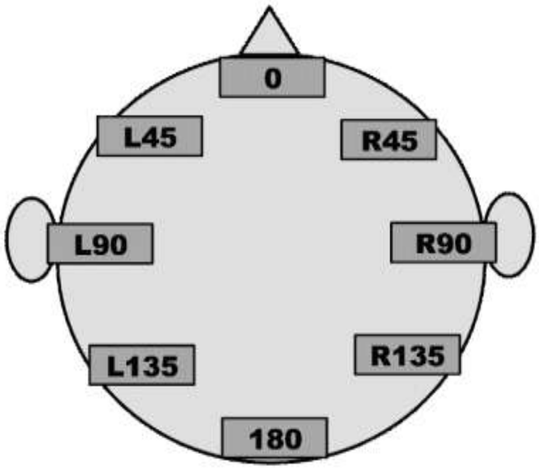
The ILD and ITD thresholds was assessed using the Three Interval Alternate Forced Choice (3IAFC) method employing two up, one down transformed staircase methods. Three bursts of white noise, two standards and one variable stimulus, were presented in a single run. White noise given at 65 dB SPL for 250 ms served as the baseline stimulus. With the exception of being provided sooner in time or with a higher intensity level than the standard stimulus, the variable stimulus was equivalent to the standard stimulus and caused ITD and ILD, respectively. As a result, the tone is lateralized to one side, leading or becoming louder in one ear. In the right ear, the changing tone always dominates or is audible louder. For ITD and ILD, the variable stimulus had a beginning level of 30 ms and 20 dB SPL. A step size of 2 ms was used for the ITD task and 2 dB was used for the ILD task (Kumar et al., 2017). The time or level of the variant stimuli was varied in accordance with the response of the subject. The test was terminated after ten reversals, and the last four reversals was averaged to get the ILD and ITD thresholds.

3.3.2. Test of spatial acuity using virtual sources under headphones [Virtual Acoustic Spatial Identification (VASI test)].

VAS stimuli are internalized sound perceptions that give the appearance of free-field sound when used with a closed-field audio device, such as headphones (King et al., 2001). The stimulus had 250 ms of WBN. To create eight VAS perceptive, the generated stimuli was delivered through headphones at the following azimuths: 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, and 135° azimuth towards the left. A consistent height of 0° azimuth and a distance of 1 m were shared by all stimuli. Presentation and collection of the responses was controlled using Paradigm experimental builder software. The user interface displayed a dummy head with eight locations corresponding to the eight VAS stimuli. It is represented in the figure 3.1. Stimuli were randomly presented at these virtual locations using the software.

Figure 3.1.

The user interface of the virtual acoustic space identification (VASI) test.



The scores for the above-mentioned tests was obtained for the dancers, musicians and control group.

Chapter 4

Results

The current study compared the differences in the auditory spatial processing abilities using Virtual auditory space identification (VASI), Inter-aural level difference (ILD) & Inter-aural time difference (ITD) in formally trained Bharatanatyam dancers, formally trained Vocal musicians and individuals with no formal training of dance and/or music. Ninety-two females belonging to an age range of 18 to 25 years were recruited for the study. The participants were grouped into three groups, group I of control participants (individuals with no formal training of dance and music) (N=30), group II consisted of formally trained Bharatanatyam dancers (N=32), and group III consisted of formally trained vocal musicians (N=30). All the obtained data were analyzed using statistical package of social science (SPSS) software version 26.0. The Shapiro Wilk's test of normality was administered to check whether the raw data is normally distributed or not and it was found to be not normally distributed ($p < 0.05$). Hence, the non-parametric tests were chosen for further analysis.

The following statistical analysis was done across the group.

- Descriptive statistics was done to estimate the mean, mean rank, median, standard deviation and inter quartile range for all tests.
- Kruskal-Wallis test was done between formally trained Bharatanatyam dancers, vocal musicians and control group to find the significant difference across the entire test.
- The Spearman's rank correlation was done to assess the relationship between formally trained Bharatanatyam dancers, vocal musicians and control group.

The results of the study are explained under following headings:

4.1. VASI scores obtained by control group, formally trained Bharatanatyam dancers, vocal musicians.

4.2. ILD thresholds obtained by control group, formally trained Bharatanatyam dancers, vocal musicians.

4.3. ITD thresholds obtained by control group, formally trained Bharatanatyam dancers, vocal musicians.

4.4. Correlation between VASI scores and ILD & ITD thresholds in formally trained Bharatanatyam dancers.

4.5. Correlation between VASI scores and ILD & ITD thresholds in formally trained vocal musicians.

4.1. VASI scores obtained by control group, formally trained Bharatanatyam dancers, vocal musicians

Descriptive statistics was carried out to find out mean, mean rank, median, standard deviation and Interquartile range of VASI scores among three group of participants. The data showed that the individuals with formal Bharatanatyam training had higher mean rank followed by individuals with formal vocal music training and lowest mean rank was obtained by control group. This is represented in Table 4.1.1.

Table 4.1.1

Mean, mean rank, Median, Standard Deviation and Interquartile Range values of VASI scores obtained by Control group, formally trained Bharatanatyam dancers and Carnatic musicians.

Group	Mean	Median	Std Deviation	Interquartile Range	Mean rank
Control Group	36.93	36.00	8.457	13	37.83
Dancers	44.00	43.00	8.088	13	58.16
Musicians	39.00	38.00	6.908	10	42.73

Kruskal-Wallis test was carried out to see the significant difference in VASI score across three groups. The results showed that there was a significant difference ($p < 0.05$) between control group & Bharatanatyam Dancers and Bharatanatyam dancers & Vocal Musicians. However, there was no significant difference ($p > 0.05$) found between Control group and vocal Musicians. The findings are depicted in table 4.1.2.

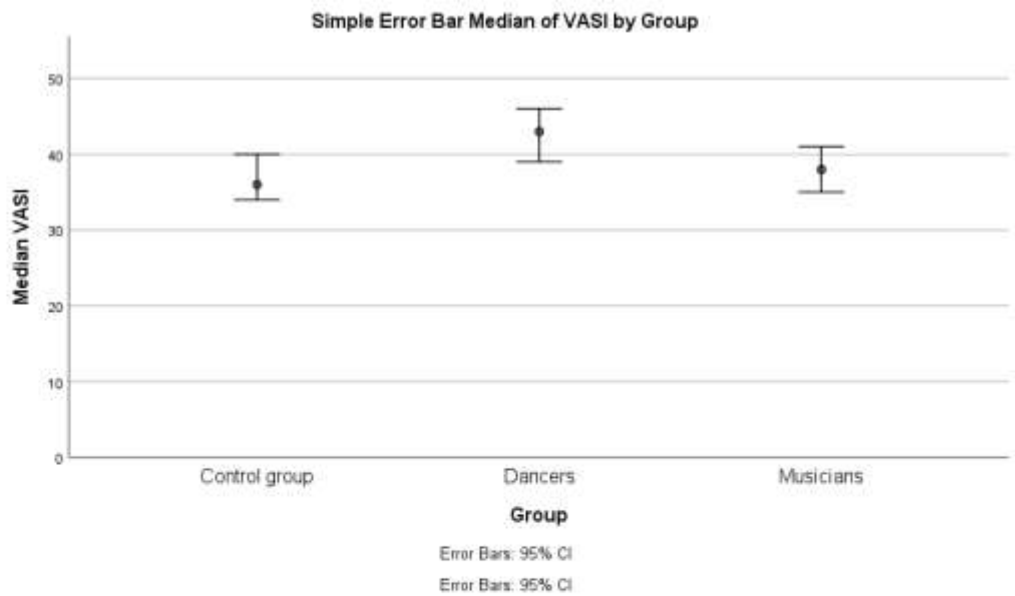
Table 4.1.2

Kruskal-Wallis results for pairwise comparison between groups.

Groups	Test Statistic	Std. Error	Std. Test Statistic	Sig.
Control group-Musicians	-4.900	6.884	-0.712	.477
Control group-Dancers	-20.323	6.776	-2.999	.003
Musicians-Dancers	15.423	6.776	2.276	.023

Figure 4.1.

The median scores for the VASI scores among the three groups.



4.2. ILD thresholds obtained by Control group, formally trained Bharatanatyam dancers, vocal musicians.

Descriptive statistics was carried out to find the mean, mean rank, median, standard deviation and Interquartile range of ITD thresholds by all the groups. The data showed that the individuals with formal Bharatanatyam training had least mean rank compared to Control group and formally trained vocal musicians. Findings are represented in Table 4.2.1

Table 4.2.1

Mean, Mean rank, Median, Standard Deviation and Interquartile Range values of ILD thresholds scores obtained by Control group, formally trained Bharatanatyam dancers and vocal musicians.

Group	Mean	Median	Std. Deviation	Interquartile Range	Mean rank
Control Group	3.9483	4.0000	1.18026	1.56	60.15
Dancers	2.8163	2.7500	0.73139	1.39	30.23
Musicians	3.4243	3.3500	0.55454	0.75	50.20

Kruskal-Wallis test was done to see the significant difference across groups. Results showed that there was significant difference ($p < 0.05$) between the two groups, formally trained Bharatanatyam dancers & control group and formally trained Bharatanatyam dancers & vocal musicians. There was no significant difference ($p > 0.05$) found in scores between control group and vocal musicians. This is depicted in table 4.2.2.

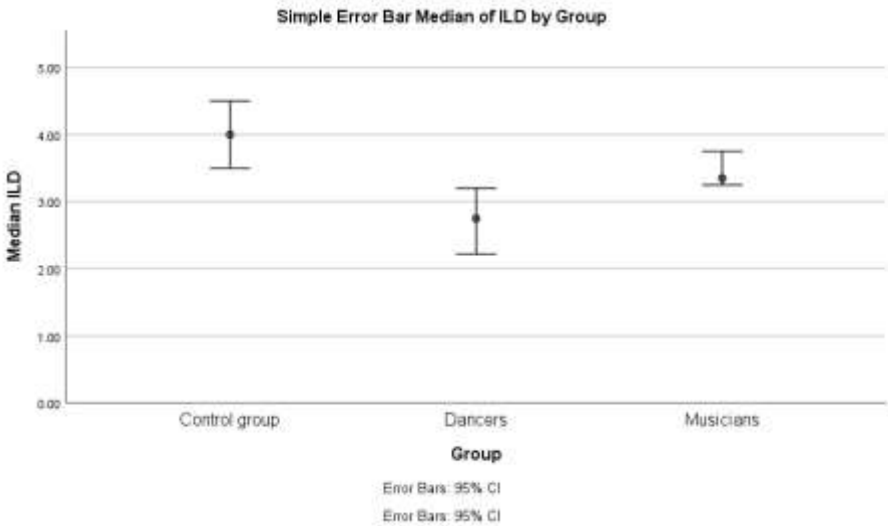
Table 4.2.2.

Kruskal-Wallis results for pairwise comparison between groups

Groups	Test Statistic	Std. Error	Std. Test Statistic	Sig.
Dancers – Musicians	-19.966	6.767	-2.950	.003
Control group-Dancers	29.916	6.767	4.421	.000
Musicians-control group	9.950	6.875	1.447	.444

Figure 4.2.

The median scores for the ILD thresholds among the three groups.



4.3. ITD thresholds obtained by Control group, formally trained Bharatanatyam dancers, Vocal musicians.

Descriptive statistics was carried out to find the mean, mean rank, median, standard deviation and Interquartile range of ITD thresholds by all the groups. The data showed that the individuals with formal Bharatanatyam training had lowest mean rank followed by formally trained vocal musicians. Highest mean rank was observed in Control group. This is represented in Table 4.3.1.

Table 4.3.1.

Mean, Mean rank, Median, Standard Deviation and Interquartile range values of ITD thresholds scores obtained by Control group, Formally trained Bharatanatyam dancers and Vocal musicians.

Group	Mean	Median	Std Deviation	Interquartile Range	Mean rank
Control Group	.6427	.4640	.33941	.66	67.78
Dancers	.2831	.2600	.10615	.18	27.86
Musicians	.3847	.3500	.16667	.11	45.10

Kruskal-Wallis test was done to see significant difference across groups. The results showed there was a significant difference ($p < 0.05$) between all the three groups. This is depicted in table 4.3.2.

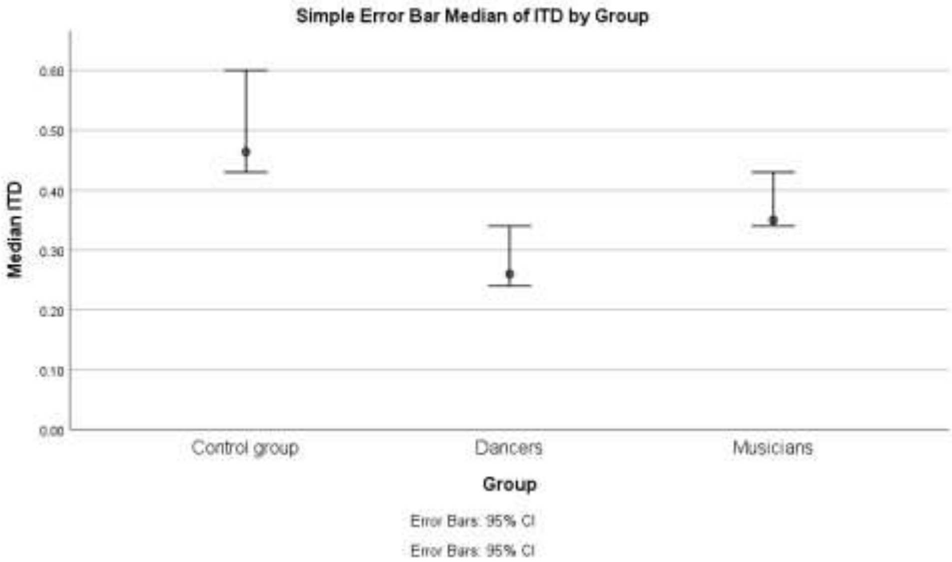
Table 4.3.2.

Kruskal-Wallis results for pairwise comparison between groups

Groups	Test Statistic	Std. Error	Std. Test Statistic	Sig.
Dancers – Musicians	-17.241	6.764	-2.549	.011
Dancers - Control group	39.924	6.764	5.903	.000
Musicians-control group	22.683	6.872	3.301	.001

Figure 4.3.

The median scores for the ITD thresholds among the three groups.



4.4. Correlation between VASI scores and ILD & ITD thresholds in formally trained Bharatanatyam dancers.

Correlation between VASI scores and ILD & ITD thresholds was established using Spearman rank correlation which revealed a significant negative correlation at the level of $p < 0.01$ between ILD & ITD threshold and VASI scores. Table 4.4.1 shows the correlation coefficients between VASI scores and ILD & ITD thresholds in formally trained Bharatanatyam dancers and it is noted that the relationship was stronger for ITD and VASI.

Table 4.4.1

Correlation coefficients between VASI scores and ILD & ITD thresholds in formally trained Bharatanatyam dancers

		ILD	ITD	VASI
ILD	Correlation Coefficient	1.000	.778**	-.897**
	Sig. (2 tailed)	-	.000	.000
	N	32	32	32
ITD	Correlation Coefficient	.778**	1.000	-.888**
	Sig. (2 tailed)	.000	-	.000
	N	32	32	32
VASI	Correlation Coefficient	-.897**	-.888**	1.000
	Sig. (2 tailed)	.000	.000	-
	N	32	32	32

** Correlation is significant at $p < 0.01$ level

4.5. Correlation between VASI scores and ILD & ITD thresholds in formally trained Vocal musicians.

Spearman rank correlation revealed significant negative correlation between ILD & ITD threshold and VASI scores in formally trained vocal musicians. Table 4.5.1 shows the correlation coefficients between VASI scores and ILD & ITD thresholds in formally trained vocal musicians.

Table 4.5.1

Correlation coefficients between VASI scores and ILD & ITD thresholds in formally trained vocal musicians.

		ILD	ITD	VASI
ILD	Correlation Coefficient	1.000	.744**	-.655**
	Sig. (2 tailed)	.	.000	.000
	N	30	30	30
ITD	Correlation Coefficient	.744**	1.000	-.772**
	Sig. (2 tailed)	.000	.	.000
	N	30	30	30
VASI	Correlation Coefficient	-.655**	-.772**	1.000
	Sig. (2 tailed)	.000	.000	.
	N	30	30	30

** Correlation is significant at $p < 0.01$ level

Overall, the test results revealed a significant difference in ILD threshold, ITD threshold and VASI scores in formally trained Bharatanatyam dancers. Hence, the first, second and third null hypothesis were rejected. Correlation analysis showed there was a significant negative correlation between ILD & ITD thresholds and VASI scores in both formally trained Bharatanatyam dancers and formally trained Vocal musicians. Hence fourth and fifth null hypothesis was also rejected.

Chapter 5

Discussion

The current study compared the differences in the auditory spatial processing abilities using Virtual auditory space identification (VASI), Inter-aural level difference (ILD) & Inter-aural time difference (ITD) in formally trained Bharatanatyam dancers, formally trained Vocal musicians and individuals with no formal training of dance and/or music. The results of the study are discussed under following headings:

5.1. Comparison of VASI scores obtained by control group, formally trained Bharatanatyam dancers, vocal musicians.

5.2. Comparison of ILD thresholds obtained by control group, formally trained Bharatanatyam dancers, vocal musicians.

5.3. Comparison of ITD thresholds obtained by control group, formally trained Bharatanatyam dancers, vocal musicians.

5.4. Relationship between VASI scores and ILD & ITD thresholds in formally trained Bharatanatyam dancers.

5.5. Relationship between VASI scores and ILD & ITD thresholds in formally trained vocal musicians.

5.1. Comparison of VASI scores obtained by control group, formally trained Bharatanatyam dancers, vocal musicians.

The VASI scores obtained by the control group, formally trained Bharatanatyam dancers, and vocal musicians were compared in this study. Individuals with no formal Bharatanatyam or musical training had considerably lower VASI scores than those with formal Bharatanatyam or musical training. The significantly lower VASI score reported in the present study in the control group is consistent with the findings of an earlier perceptual auditory information of reverberation and its effect in space perception based experiment (Kaplanis & VanVelzen, 2012). In the same study they reported that musicians have superior space perception in tasks primarily involving vertical distance discrimination. Several functional imaging studies have demonstrated differences between musicians and non-musicians in motor, auditory, and somatosensory tasks (Pantev et al., 1998; Schlaug, 2001). A few studies have found that there is a structural brain differences in corpus callosum, motor cortex and cerebellum between musicians and non-musicians. They concluded that unique musical abilities and absolute pitch could be due to this neural basis. This ability may be related to a region in the human brain (planum temporale) that is preferentially activated in musicians with absolute pitch during tone tasks (Schlaug et al., 1995a,b; Schlaug, 2001; Schneider et al., 2002; Hutchinson et al., 2003).

Dance is an art form that has a strong association to music (Pisharody et al., 2016). Dance instruction, like musical training, emphasizes the perception of temporal components of sound when body motions are supposed to be in rhythm with it (Bulkin et al., 2006). Dance is an expression of space and time that communicates via the control of body movement and gestures (Anderson, 2010). Dance and music complement each other (Nor & Stepputat, 2016), and the dancer's body and music attune with each other to communicate the intricacies of rhythm through body movements (Ramaswamy & Deslauriers, 2014). While musicians educate their ears to detect subtle temporal, volume, and pitch variations in music, dancers portray these variations with their bodies. Dancers, on the other hand, must auditorily analyze those details and replicate them in terms of motor motions. People move their bodies as a natural response to music or auditory stimuli (Brown et al., 2000). These describe how audio temporal signals interact with bodily movements in musicians. From the foregoing, it is possible to conclude that body movements and auditory temporal processing are related, and that body movements are most likely linked to auditory processing of temporal features of music.

In the present study Kruskal Wallis tests revealed that there was significant difference in VASI scores between Bharatanatyam dancers & control group and Bharatanatyam dancers & Vocal musicians. The Virtual source identification (VASI) test complements the localization test by inferring spatial acuity utilizing the same sources (virtual auditory sources) within the head. The spatial perception task of the VASI involves multiple cues in the stimuli for presentation. Integration of all three cues of spatial perception, that is, intensity, frequency, and time which facilitates precise spatial judgment. From the results obtained, it is well understood that formally trained Bharatanatyam dancers had a superiority in VASI scores when compared to both the groups which enables better processing of binaural cues. There were several studies which quoted that dance training has a direct impact on the auditory system. The plasticity of the efferent auditory system increased with regular dance training and dance can be used as a tool to improve auditory attention (Joseph et al., 2019). A correlation between body movements and auditory temporal processing ability was drawn by Suzuki et al. (2013) wherein they investigated using a typical temporal-bisection paradigm, in which the slope of the temporal-bisection function serves as a measure of temporal sensitivity. The bisection slope for auditory time perception was steeper when individuals initiated each auditory stimulus sequence with a keypress than when they passively heard each sequence, indicating that introduction of an action improves auditory temporal sensitivity. Body movements tend to synchronize with auditory rhythms rather than visual rhythms (Patel et al., 2005; Repp & Penel, 2004), and movements influence auditory rhythm perception (Phillips-Silver & Trainor, 2005;

2007). Furthermore, auditory processing tends to yield superior temporal sensitivity and to dominate visual processing in the perception of timing and duration (Hirsh & Sherrick, 1961; Shipley, 1964; Penney et al., 2000; Shams et al., 2000; Aschersleben & Bertelson, 2003; Morein-Zamir et al., 2003; Droit-Vole et al., 2004; Wearden et al., 2006; Burr et al., 2009).

The advantage of dance training, on auditory temporal processing was found that dance has a positive on the auditory temporal resolution, as assessed by the Gap In Noise test (Silva et al., 2014). Furthermore, basal ganglia are crucial in controlling voluntary movements (Hoover, & Strick, 1993), and continuous music used in dance training is thought to increase top-down regulation of the basal-ganglia to the auditory cortex (Poikonen et al., 2016). Furthermore, there is structural evidence linking basal ganglia neural activity to sensory operations (Middleton & Strick, 2000). All these studies correlate with the results obtained in the present study that there is an extra lead in VASI scores in Bharatanatyam dancers.

5.2. Comparison of ILD thresholds obtained by control group, formally trained Bharatanatyam dancers, vocal musicians.

Individuals with Bharatanatyam training had significantly lower thresholds of ILD indicative of better processing of binaural cues. Kruskal-Wallis test results showed that there was significant difference ($p < 0.05$) between the two groups, formally trained Bharatanatyam dancers & control group and formally trained Bharatanatyam dancers & vocal musicians. Perception of sounds is very important for both dancers and musicians. Dancers have to carefully listen to each beat and perform rapid body movements. Dance instruction, like musical training, emphasizes the perception of temporal components of sound when body motions are supposed to be in rhythm with it. While musicians educate their ears to detect subtle temporal, volume, and pitch variations in music, dancers portray these variations with their bodies. Dancer and musicians have better temporal processing (Silva et al., 2016). Thus, this leads to conclusion that individuals who received dance or music training can detect subtle changes in signal better than individuals with no training in music and dance.

5.3. Comparison of ITD thresholds obtained by control group, formally trained Bharatanatyam dancers, vocal musicians.

Individuals who had received Bharatanatyam training had considerably lower ITD thresholds. The Kruskal-Wallis test revealed a significant difference ($p < 0.05$) between the two groups, formally trained Bharatanatyam dancers and the control group, and formally trained Bharatanatyam dancers and vocal musicians. Sound perception is critical for both dancers and musicians. Dancers must pay close attention to each beat and perform quick body motions. Like musical training, dance teaching emphasizes the awareness of temporal components of sound when body actions are expected to be in sync with it. Dancers express these variations with their body, however musicians train their ears to perceive small temporal, loudness, and pitch variations in music. Dancers and musicians have stronger temporal processing abilities (Silva et al., 2016). This correlates well with results obtained in the present study that individuals with formal Bharatanatyam training and vocal musicians had betters ITD.

5.4. Relationship between VASI scores and ILD & ITD thresholds in formally trained Bharatanatyam dancers.

The association between VASI scores, ILD and ITD thresholds was established using Spearman rank correlation, which demonstrated a significant negative correlation between ILD & ITD threshold and VASI scores at the level of 0.02 in formally trained Bharatanatyam dancers. Negative correlation indicates that with increase in VASI scores there was a significant reduction in both ILD and ITD thresholds which lead to a conclusion that individuals with higher VASI scores had better ILD and ITD thresholds. Sanjana et al., (2022) discovered a stronger association between psychoacoustic tests (ITD, ILD, and VASI) in children who had received abacus training. Abacus training induces brain reorganisation, and several studies quoted that dance training has a direct impact on the auditory system. The plasticity of the efferent auditory system increased with regular dance training and dance can be used as a tool to improve auditory attention (Joseph et al., 2019). This explains the relationship obtained in the present study.

5.5.Relationship between VASI scores and ILD & ITD thresholds in formally trained vocal musicians.

The association between VASI scores, ILD and ITD thresholds was established using Spearman rank correlation, which demonstrated a significant negative correlation between ILD & ITD threshold and VASI scores at the level of 0.02 in formally trained Vocal musicians. Negative correlation indicates that with increase in VASI scores there was a significant reduction in both ILD and ITD thresholds which lead to a conclusion that individuals with higher VASI scores had better ILD and ITD thresholds. Sanjana et al., (2022) discovered a stronger association between psychoacoustic tests (ITD, ILD, and VASI) in children who had received abacus training. Abacus training induces brain reorganisation, and similarly studies have found that there is a structural brain differences in corpus callosum, motor cortex and cerebellum between musicians and non-musicians (Schlaug et al., 1997a). This explains the relationship obtained in the present study.

Chapter 6

Summary and Conclusion

The current study compared the differences in the auditory spatial processing abilities using Virtual auditory space identification (VASI), Inter-aural level difference (ILD) & Inter-aural time difference (ITD) in formally trained Bharatanatyam dancers, formally trained Vocal musicians and individuals with no formal training of dance and/or music. Further, the present study highlights the benefit of Bharatanatyam training on coding of sound signals in the auditory system.

Ninety-two females belonging to an age range of 18 to 25 years were recruited for the study. The participants were grouped into three groups, group I of control participants (individuals with no formal training of dance and music) (N=28), group II consisted of formally trained Bharatanatyam dancers (N=32), and group III consisted of formally trained vocal musicians (N=28). Tests of spatial acuity (VASI, ILD and ITD) was administered. All the obtained data were analyzed using statistical package of social science (SPSS) software version 26.0.

VASI performance in individuals with formal Bharatanatyam training had a higher mean rank, followed by those with formal vocal music training, while the control group had the lowest rank. Individuals with formal Bharatanatyam training had the lowest mean rank in ILD thresholds, followed by formally trained vocal musicians, and the control group had the highest. Individuals with formal Bharatanatyam instruction and formally trained vocal musicians performed better in ITD thresholds than the Control group. Between ILD & ITD thresholds and VASI scores, there was a significant strong negative association in both individuals with formal Bharatanatyam training and formally trained vocal musicians. Dancers performed superior to both formally trained musicians and control group in all the spatial acuity tests. Thus, it can be concluded that Bharatanatyam dance training has a significant impact on coding of sound signals in the auditory system.

To conclude the results obtained from the current study suggests that the VASI test is more sensitive in measuring differences in auditory spatial processing. Unlike the ITD and ILD, the VASI spatial perception task contains several cues in the stimuli during presentation. These include the integration of all three spatial perception cues, generally intensity, frequency, and time. The incorporation of all signals allows for more exact spatial judgements, which is evident, making the VASI the most sensitive spatial perception test.

Implication of the study

The discoveries of the current study will further knowledge of the coding of sound signals in the auditory systems of people who have had extensive, professional dance training. Studies that have sought to investigate dancers with formal training's hearing talents have been quite rare. Therefore, this study would add to the body of knowledge already established in the field. People of all ages, from young children to adults, participate in formal dance training as an extracurricular activity. To raise awareness among the general public, research on the complementary functional impacts on other physiological systems would be helpful.

Limitations and Future Directions

The study was limited to females aged between 18 to 25 years. In present study only formally trained Bharatanatyam dancers were considered, further studies can be done using other dance forms. The current study's behavioural measures were all conducted with noise as stimulus. Taking this as a guide, future study can be directed towards understanding the impacts using more ecologically valid stimuli such as speech.

Traditional waveform analysis for determining speech ABR peak latency and amplitude can be combined with behavioural measures to quantify any changes between the three groups. Thus, speech ABR can be used as a sensitive test to discover the differences between groups. Spatiotemporal analysis must be included in addition to classic waveform studies to follow subtle changes generated by effect of training that may not be easily apparent in conventional analyses.

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