

**EFFECT OF AGE ON PSYCHOACOUSTIC ABILITIES, SPEECH
PERCEPTION IN NOISE AND AUDITORY COGNITIVE ABILITIES IN
MUSICIANS AND NON-MUSICIANS**

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LIST OF ABBREVIATIONS

SPiN- Speech Perception in Noise

PDT- Pitch Discrimination Threshold

DDT- Duration Discrimination Threshold

GDT- Gap Detection Threshold

MLP- Maximum Likelihood Procedure

BDS- Backward Digit Span

RS- Reading Span

SNR- Signal to Noise Ratio

PCA- Principal Component Analysis

Mini-PROMS- Mini Profile of Music Perception Skills

ELMEQ- Edinburgh Lifetime Musical Experience Questionnaire

WHOQOL-BREF- World Health Organization Quality of Life Brief Questionnaire

MMSE- Mini-Mental State Examination

SCAP-A- Screening Checklist for Auditory Processing- Adults

ICC- Intraclass Correlation Coefficient

ANOVA- Analysis of Variance

OPERA- Overlap Precision Emotion Repetition Attention

ABSTRACT

Research in psychoacoustics, speech perception in noise (SPiN), and the cognitive domain, particularly working memory, has consistently demonstrated superior performance in musicians compared to non-musicians. However, it remains unclear whether these advantages persist uniformly across different age groups and to what extent musical training can attenuate age-related declines in auditory and cognitive functions. Given the high prevalence of perceptual and cognitive deterioration in the aging population, it is worthwhile to investigate whether musical training provides a protective effect throughout the lifespan.

The present study examined the influence of musical training on psychoacoustic, SPiN, and working memory abilities across five age groups (10 to <20, 20 to <30, 30 to <40, 40 to <50, and 50 to <60 years) using a cross-sectional design with 181 participants (91 musicians, 90 non-musicians). Musicians had a minimum of 5 years (for the younger group) to 10 years (for other age groups) of Carnatic classical training. Psychoacoustic abilities, primarily pitch and duration discrimination, and gap detection thresholds, were measured using the maximum likelihood procedure in MATLAB. Musicians showed absent or delayed age-related decline, compared to non-musicians, who exhibited deterioration from middle age onwards. SPiN abilities, assessed using the Kannada Sentence Identification Test in four-talker babble at +5, 0, and -5 dB signal-to-noise ratios (SNRs), revealed that musicians had a slower rate of decline at lower SNRs and better performance than non-musicians across all SNRs and age groups. Working memory, evaluated using Backward Digit Span and Reading Span tasks (using Smriti-Shravan software), showed no significant age-related decline in musicians, while non-musicians demonstrated reduced performance with age (on the Backward Span task). Musicians outperformed non-musicians, particularly in middle and older age groups, on both tasks.

A non-parametric Principal Component Analysis was performed separately for musicians and non-musicians to explore relationships among age, psychoacoustic, SPiN, and working memory measures. In non-musicians, age, pitch discrimination, gap detection, and percent correct SPiN scores (-5 dB SNR) were significantly correlated. Working memory was also linked to percent correct SPiN scores (+5 and 0 dB SNRs) and the duration discrimination tasks. Among musicians, pitch discrimination correlated with working memory, while gap detection was associated with SPiN and age, indicating that SPiN and working memory were uncorrelated. Overall, the results suggest that musical training may protect against age-related auditory and cognitive decline, thereby enhancing psychoacoustic abilities, SPiN performance, and working memory, and ultimately supporting healthy perceptual and cognitive aging.

CHAPTER 1

INTRODUCTION

The global population of aging individuals is increasing rapidly. By 2030, one in six people worldwide will be aged 60 years or older, with this group projected to grow from 1 billion in 2020 to 1.4 billion by 2030. By 2050, the number is expected to double to 2.1 billion, while the population aged 80 and above is projected to triple to 426 million (World Health Organization, 2019). According to the United Nations Population Fund's 2023 India Ageing Report, India's elderly population (aged 60 years and above) is steadily rising from 7% (88 million) in 2009 to 10.5% in 2022, and projected to reach 20.8% (over 315 million) by 2050 and over 36% by 2100 (Challenges related to aging population, 2025; Subaiya & Bansod, 2011).

Aging is associated with anatomical and physiological changes in the auditory system at both peripheral and central levels (Frisina, 2001; Lister et al., 2011). Several studies have reported a decline in auditory abilities with age, even among individuals with normal peripheral hearing acuity (Alain et al., 2004; Betlejewski, 2006; Frisina & Walton, 2006; George & Coch, 2011; Ouda et al., 2015; Profant et al., 2019). Older adults often experience difficulty with speech perception in noise (SPiN), leading to communication challenges (Fostick & Babkoff, 2013; Kemper & Lacal, 2004; Kim & Oh, 2013; Kocabay et al., 2022; Wong et al., 2010). In addition to declining auditory function, aging is also accompanied by deterioration in cognitive and memory functions, particularly working memory, which further contributes to perceptual difficulties in older individuals (Akeroyd, 2008; Arlinger et al., 2009; Houtgast & Festen, 2008; Humes, 2005).

A growing body of evidence suggests that musicians consistently exhibit better performance than non-musicians in the fundamental auditory, cognitive, and

language-related tasks (Bidelman et al., 2011; Fujioka et al., 2004; Fujioka et al., 2005; George & Coch, 2011; Heinrich et al., 2008; Ho et al., 2003; Koelsch et al., 1999; Micheyl et al., 2006; Moreno, 2009; Talamini et al., 2016). Neuroimaging studies indicate that musical engagement recruits a broad and distributed neural network, including frontal, parietal, temporal, limbic, and cerebellar regions (Särkämö et al., 2014; Sihvonen & Särkämö, 2022; Toader et al., 2023).

Furthermore, both behavioral and electrophysiological findings demonstrate that musical training enhances auditory processing skills, contributing to superior performances in auditory memory, SPiN, frequency and temporal resolution, auditory stream segregation, multisensory integration, and executive functioning (Chan et al., 1998; Chandrasekaran & Kraus, 2010; Micheyl et al., 2006; Parbery-Clark et al., 2009a; Rammsayer & Altenmüller, 2006; Tervaniemi et al., 2005). Importantly, these enhancements appear to be experience-dependent, with stronger effects observed in individuals with sustained and intensive musical practice.

Interestingly, age-related decline in auditory abilities and music training–related enhancements appear to occur in overlapping domains. The following sections elaborate on the functional and anatomical changes associated with both musical training and aging.

Music training-associated changes in the auditory system

Structural and functional changes

Long-term musical training is associated with significant structural and functional changes in the auditory system. These include greater grey matter density in left Heschl's gyrus, left cerebellum, left inferior frontal gyrus, the superior parietal cortex, and the precentral gyrus (Gaser & Schlaug, 2003; Schlaug, 2001), as

well as increased activity in auditory areas (Gaab & Schlaug, 2003). Musicians also utilize right-hemisphere areas to better distinguish speech sounds, possibly expanding their language network. Musical training appears to enhance sensitivity to the acoustic and temporal aspects of speech, partly through the involvement of right-hemisphere regions that mirror speech-processing areas (Jantzen et al., 2014; Zatorre et al., 2002). Several studies have reported enhanced brain plasticity and adaptive neural changes resulting from musical training (Gaser & Schlaug, 2003; Habib & Besson, 2009; Zatorre, 2005). For instance, veena players exhibit stronger auditory cortex responses specifically to veena tones, which are linked to early training and the duration of practice, highlighting experience-driven plasticity.

Psychoacoustics, Speech perception in noise, and Cognition

Previous studies have shown that musicians perform better than non-musicians in tasks involving frequency, intensity, and duration discrimination, and temporal processing (Chan et al., 1998; Espinoza-Varas et al., 2019; McAdams et al., 1999; Micheyl et al., 2006; Rammsayer & Altenmüller, 2006; Tervaniemi et al., 2005). Neurophysiological evidence further indicates that musicians demonstrate stronger event-related potentials when processing pitch patterns and detecting irregularities in musical grammar (Fujioka et al., 2004; Koelsch et al., 1999). The frequency-following response studies have shown that musicians exhibit better neural synchronization to pitch compared to non-musicians (Rodrigues et al., 2019; Sanfins et al., 2020). Additionally, musicians demonstrate superior speech comprehension in noisy environments and enhanced sensitivity to sentence prosody (Deguchi et al., 2012; Monteiro et al., 2010; Rammsayer & Altenmüller, 2006; Rana et al., 2014; Sangamanatha et al., 2012). These findings suggest that musical training strengthens

speech perception and listening skills in both optimal and adverse listening environments.

Musicians exhibit superior cognitive skills, including improved working memory (Chan et al., 1998) and heightened auditory attention (Strait et al., 2010). Musicians are reportedly better than non-musicians in broader cognitive domains, such as problem-solving and overall intelligence (Schellenberg, 2006; Tierney & Kraus, 2013). It is reported that music training is associated with enhanced digit span performance (Fujioka et al., 2006; Kumar & Krishna, 2019), including both Forward Digit Span and Backward Digit Span (Talamini et al., 2016), as well as improved reading of complex words (Moreno, 2009). Thus, musicians demonstrate superior cognitive and working memory abilities compared to non-musicians.

Age-related changes in the auditory system

Structural and functional changes

Aging leads to anatomical and physiological changes in the auditory system, particularly in the inner ear and neural pathways (Howarth & Shone, 2006). While outer and middle ear changes have a minimal impact, aging causes the loss of hair cells, ganglion cells, and reduced blood flow in the cochlea, particularly in the stria vascularis, which affects cochlear potentials (Jayakody et al., 2018; Schuknecht & Gacek, 1993). Degeneration also occurs in the brainstem and auditory cortex (Presacco et al., 2016, 2019). A key age-related change is the loss of neuronal synchronization, accompanied by reduced excitation and inhibition, which leads to degraded neural encoding in the central auditory system (Frisina & Walton, 2006; Tremblay et al., 2003). In summary, aging results in degeneration of cochlear and neural structures, reduced inhibition, and impaired auditory processing.

Psychoacoustics, Speech perception in noise, and Cognition

Age-related anatomical and physiological changes in the auditory system lead to a decline in auditory processing among older adults, affecting SPiN abilities (Füllgrabe et al., 2015; Humes et al., 2013; Schoof & Rosen, 2016). Pitch discrimination declines with age, with a gradual decline from 25 to 55 years and sharper deterioration after 55 (König, 1957). Older adults show significantly larger frequency difference limens at 500 Hz and 1000 Hz compared to young adults (Clinard et al., 2010; Harris et al., 2008; He et al., 2007; Lentz et al., 2022; Tao et al., 2023). While some studies report no consistent age differences in gap detection (Fitzgibbons & Gordon-Salant, 1994; Lister et al., 2000, 2002), older adults consistently show poorer duration discrimination and greater variability in performance than younger individuals (Abel et al., 1990; Bergeson et al., 2001; Fitzgibbons & Gordon-Salant, 1994, 1995). Aging is associated with a significant decline in working memory abilities (Ciorba et al., 2011; Ding et al., 2016; Matysiak et al., 2019). Even with preserved hearing, older adults often exhibit a decline in perceptual and cognitive functioning (Houtgast & Festen, 2008). Working memory decline is reported to begin in middle age and progressively worsen with advancing age (Bucur & Madden, 2010; Burke & Barnes, 2006; Davis et al., 1990). Thus, aging leads to a deterioration in auditory and speech perception abilities, accompanied by a reduction in working memory performance.

Need for the Study

As the brain ages, structural and functional changes lead to slower cognitive processing, reduced working memory, diminished executive function, and poorer temporal resolution, making speech perception more difficult (Gordon-Salant et al., 2006; Pichora-Fuller & Souza, 2003; Raz et al., 2005). These functional deficits are

further worsened by age-related hearing loss and synaptopathy (Bharadwaj et al., 2014). Synaptopathy refers to the loss of synaptic connections between the cochlear inner hair cells and the auditory nerve fibers, resulting in speech-in-noise difficulties despite normal hearing sensitivity (Liberman & Kujawa, 2017).

Neurogenesis, the process of forming new neurons in the brain, is essential for brain development, repair, and plasticity. Though it is most active before birth, it continues across the lifespan but declines with age (Eriksson et al., 1998; Kuhn et al., 1996). Musical training, started from childhood, promotes neuroplasticity and enhances auditory processing by stabilizing neural circuits and supporting auditory function. It also facilitates the reorganization of existing neurons and the formation of new ones as a result of regular practice (Hyde et al., 2009; Münte et al., 2002; Toader et al., 2023). Thus, such extended musical training may help preserve subcortical timing in older adults, counteracting age-related auditory decline (Anderson et al., 2012).

Indian classical music, particularly Carnatic music, is characterized by intricate melodic and rhythmic structures that incorporate microtones and gamakas, offering cognitive benefits such as enhanced memory, improved spatial reasoning, and stress relief (Amemane et al., 2020; Kour et al., 2012; Nisha et al., 2022). Unlike Western music, which emphasizes melody and rhythm, Indian classical music is built on Raga and Tala (Moreno, 1988). Ragas are sequential note patterns that evoke emotions. The two main traditions—South Indian Carnatic and North Indian Hindustani—differ in structure, with Carnatic music being more detailed and systematic (Amemane et al., 2020; Vyas et al., 2015). The earlier evidence suggests that aging and musical training may have opposing effects on auditory and cognitive abilities (Nisha et al., 2022; Strait & Kraus, 2014; Zendel & Alain, 2012). Hence,

investigating these abilities across the lifespan can help clarify how age and musical training interact, help identify sensitive periods for maximal benefit from music (Strait & Kraus, 2014), and determine whether musical training can slow age-related decline. Such research could pave the way for deficit-targeted intervention strategies, particularly those utilizing music-based approaches, for older adults.

Despite its potential importance, no comprehensive battery of behavioral measures, particularly within the Indian context, has systematically examined the effects of Carnatic classical music training across age groups. Therefore, the present study investigates psychoacoustic processing, SPiN, and working memory in musicians and non-musicians across a broad age range.

Need to study psychoacoustic and speech perception in noise abilities

Auditory psychoacoustic abilities are often assessed through tasks that involve the discrimination of frequency, intensity, duration, and gaps. Temporal resolution is crucial for auditory processing, as duration cues play a key role in distinguishing speech sounds (Miller & Liberman, 1979). Several studies have indicated elevated discrimination and gap detection thresholds in elderly individuals (Braga et al., 2015; Grose & Mamo, 2010; Kumar & Sangamanatha, 2012; Lunardelo et al., 2024; Mussoi & Brown, 2019). In contrast, musicians generally show superior performance on psychoacoustic tasks compared to non-musicians (Bidelman et al., 2011; Micheyl et al., 2006; Tervaniemi et al., 2005). Music training sharpens perceptual skills by enhancing sensitivity to subtle acoustic cues, aiding in better noise differentiation and separation (Chasin, 2003; Sangamanatha et al., 2012). Although musical training enhances temporal resolution and auditory discrimination, it remains unclear whether it can mitigate age-related declines in perceptual abilities.

Additionally, older adults with normal hearing often struggle with SPiN difficulties (Betlejewski, 2006; Gomez & Madey, 2001), leading to social isolation and reduced quality of life. Even at suprathreshold levels, they perform poorer than younger adults on SPiN tasks (Dubno et al., 1984; Johannesen et al., 2016). As noise levels increase, listening becomes more effortful, requiring the use of working memory and attention (Heinrich et al., 2008; Pichora-Fuller et al., 2006). Approximately 40% of adults over 50 and 71% of those over 70 experience SPiN difficulties (Boncz et al., 2024; Slade et al., 2020), particularly in settings with informational masking, such as cocktail parties, due to impaired selective attention (Boncz et al., 2024).

To explain the role of musical training in improving SPiN abilities, the OPERA theory was proposed. The Overlap, Precision Emotion, Repetition and Attention (OPERA) theory (Patel, 2011) suggests that music training improves SPiN by enhancing auditory precision and engaging overlapping networks for music and speech. Despite these supporting studies, some research reports no clear SPiN advantage for musicians (Clayton et al., 2016; Ruggles et al., 2014; Swaminathan et al., 2015). Given the high prevalence of age-related SPiN difficulties, this study aims to explore whether musical training can mitigate the age-related SPiN declines. Since Carnatic music places emphasis on microtonal distinctions (Krishnaswamy, 2004), it may enhance temporal processing and auditory discrimination abilities, thereby improving speech perception (Mishra et al., 2015; Nisha et al., 2022).

Need to study working memory abilities

Cognitive impairment affects 5.1% to 41% of adults over 50, with a median prevalence of 19% (Pais et al., 2020), underscoring the need to prevent decline in working memory. Working memory is essential for language learning and planning

(Ávila et al., 2015; McAvinue et al., 2013), and its decline with age affects verbal, visuospatial, and executive components of cognition (Brown et al., 2012; Curtis et al., 2019). Common tests used to assess working memory include reading span, operation span (D'Souza et al., 2018; Franklin et al., 2008), backward digit span (Clayton et al., 2016; Zuk et al., 2014), and N-back span tasks (Ding et al., 2018; Pallesen et al., 2010).

Musicians often perform better than non-musicians in working memory tasks (George & Coch, 2011; Ho et al., 2003; Talamini et al., 2016), likely due to brain plasticity resulting from skill learning; however, some studies report no differences (Helmbold et al., 2005; Smayda et al., 2015). Musical expertise not only improves working memory but also enhances attention control (Duke et al., 2011), sensory-motor integration (Münte et al., 2002), and planning (Palmer & Drake, 1997). Thus, music training is known to strengthen working memory through the repetition and memorization of notes (Telesco et al., 2021), offering a promising approach to slow or reduce the impact of age-related cognitive decline, especially as the effectiveness of working memory training programs remains debated (Matysiak et al., 2019).

Aim of the Study

The aim of the present study was to assess the psychoacoustic abilities, speech perception in noise, and working memory abilities in musicians and non-musicians across a wide age range.

Objectives of the Study

1(a). To compare the psychoacoustic abilities across different age groups (10 to <20, 20 to <30, 30 to <40, 40 to <50, and 50 to <60 years) within musicians and non-musicians on the following measures

a. Pitch Discrimination

b. Duration Discrimination and

c. Gap Detection

1(b). To compare the psychoacoustic abilities between musicians and non-musicians within each age group on the following measures

a. Pitch Discrimination

b. Duration Discrimination and

c. Gap Detection

2(a). To compare the speech perception in noise abilities across different age groups (10 to <20, 20 to <30, 30 to <40, 40 to <50, and 50 to <60 years) within musicians and non-musicians at three different signal-to-noise ratios

a. +5 dB

b. 0 dB and

c. -5 dB

2(b). To compare the speech perception in noise abilities between musicians and non-musicians within each age group at three different signal-to-noise ratios

a. +5 dB

b. 0 dB and

c. -5 dB

3(a). To compare the working memory abilities across different age groups (10 to <20, 20 to <30, 30 to <40, 40 to <50, and 50 to <60 years) within musicians and non-musicians on the following measures

a. Backward Digit Span and

b. Reading Span

3(b). To compare the working memory abilities between musicians and non-musicians within each age group on the following measures

- a. Backward Digit Span and
 - b. Reading Span
4. To assess the relationship among age, psychoacoustic abilities, speech perception in noise, and working memory abilities in musician and non-musician groups.

Null Hypotheses

1(a). There is no significant difference in psychoacoustic abilities across different age groups (10 to <20, 20 to <30, 30 to <40, 40 to <50, and 50 to <60 years) within musicians and non-musicians on the following measures

- a. Pitch Discrimination
- b. Duration Discrimination and
- c. Gap Detection

1(b). There is no significant difference in psychoacoustic abilities between musicians and non-musicians within each age group on the following measures

- a. Pitch Discrimination
- b. Duration Discrimination and
- c. Gap Detection

2(a). There is no significant difference between speech perception in noise scores across different age groups (10 to <20, 20 to <30, 30 to <40, 40 to <50, and 50 to <60 years) within musicians and non-musicians at three different signal-to-noise ratios

- a. +5dB
- b. 0dB and
- c. -5dB

2(b). There is no significant difference in speech perception in noise scores between musicians and non-musicians within each age group at three different signal-to-noise ratios

d. +5dB

e. 0dB and

f. -5dB

3(a). There is no significant difference between the working memory abilities across different age groups (10 to <20, 20 to <30, 30 to <40, 40 to <50, and 50 to <60 years) within musicians and non-musicians on the following measures

a. Backward Digit Span and

b. Reading Span

3(b). There is no significant difference in working memory abilities between musicians and non-musicians within each age group on the following measures

c. Backward Digit Span and

d. Reading Span

4. There is no significant association between age, psychoacoustic abilities, speech perception in noise, and working memory abilities in musician and non-musician groups.

CHAPTER 2

REVIEW OF LITERATURE

Hearing plays a central role in maintaining communication and social relationships (Teixeira et al., 2011). For the auditory system to function effectively, both its peripheral and central components must work effectively. From the outer ear to the cerebral cortex, the auditory system is responsible for detecting and interpreting sounds, as well as processing those sounds that support learning and everyday interaction (Bortoletto Brossi et al., 2007). Further insight into auditory capacities is provided through the study of acoustic patterns in human languages and various musical traditions (Patel, 2010). “Music is the art of combining sounds of voices or instruments so as to achieve beauty of form and expression of emotion, and a pleasant sound” (Sykes, 1984) or “the art or science of ordering of sounds in notes and rhythms to give a desired pattern or effect” (Jacobs, 1972).

Engagement with music activates a widespread bilateral network of brain regions, including the frontal, parietal, temporal, limbic, paralimbic, and cerebellar areas, which support perception, memory, attention, language, and rhythm (Zatorre & Salimpoor, 2013). Musical training refines the brain networks and shapes how both cognitive and emotional processes unfold (Zatorre & Salimpoor, 2013). Typically beginning in childhood, such training involves years of practice that gradually sharpen sensitivity to the acoustic dimensions of sound: timing, pitch, and timbre (Kraus et al., 2009). Timing refers to markers such as onset and offset, pitch corresponds to frequency perception, and timbre conveys sound quality derived from spectral and temporal cues. A substantial body of evidence shows that these experiences transfer to non-musical contexts. Thus, musicians often demonstrate superior categorical perception, auditory memory, speech-in-noise recognition, frequency discrimination,

and temporal resolution compared to non-musicians (Chan et al., 1998; Michey et al., 2006; Parbery-Clark et al., 2009a; Rammsayer & Altenmüller, 2006; Tervaniemi et al., 2005). These outcomes are linked to higher-order skills, such as auditory stream segregation, multisensory integration, and executive control (Kraus & Chandrasekaran, 2010).

Aging induces degenerative changes in both the peripheral and central auditory pathways, leading to functional and structural modifications throughout the auditory system. The age-related decline in these abilities can be attributed to anatomical and physiological alterations within the auditory system (Schulz et al., 2022). A decrease in gray matter volume within the fronto-temporal cortex and reduced integrity of white matter microstructure contribute to central presbycusis. This condition is typically characterized by impaired auditory object recognition and deficits in higher-order auditory processing, including difficulties understanding speech in noisy environments. Reduced speech perception in noise, despite an intact peripheral auditory system, may stem from age-related declines in central auditory processing (An et al., 2025).

The current review firstly examines the impact of age and music on structural and functional brain changes. Next, it describes various types of music, highlighting their differences, and compares instrumental and vocal music. Finally, it explores psychoacoustic, speech perception in noise (SPiN), and working memory abilities, focusing on how aging and musical training affect these functions.

Age-Induced Changes in Brain Anatomy and Physiology

Aging leads to numerous changes in both the peripheral and central nervous systems. The peripheral changes include outer hair cell loss, reduced amplification, frequency selectivity, or pitch sensitivity (Schuknecht & Gacek, 1993), while declines

in neural phase-locking occur at the central level (Clinard et al., 2010). Additionally, basilar membrane stiffening reduces frequency resolution and timing sensitivity (Ruggero & Temchin, 2005), and spiral ganglion neuron loss further weakens temporal processing (Frisina & Walton, 2006; Makary et al., 2011). Furthermore, degeneration of outer hair cells and ganglion cells diminishes fine-tuning, temporal resolution, and neural transmission accuracy (Makary et al., 2011; Schuknecht & Gacek, 1993).

Central changes also degrade auditory function by disrupting subcortical pitch representation (Anderson, 1973), reducing temporal processing by the superior olivary complex (Caspary et al., 2008), lowering synchrony in the auditory brainstem (Burkard & Sims, 2002), and impairing prefrontal contributions to working memory and duration discrimination (Alain et al., 2001). Also, myelin degeneration slows neural transmission (Peters, 2002), while reduced gamma-aminobutyric acid in cortical and brainstem pathways worsens temporal resolution (Caspary et al., 2008). In addition, temporal processing declines due to altered eighth-nerve fiber recovery (Schneider & Hamstra, 1999), reduced neuronal synchrony (Alain et al., 2004), and weaker inhibition, which affects their SPiN abilities (Bertoli et al., 2002).

Music training-induced changes in Brain Anatomy and Physiology

Musical training induces extensive structural and functional reorganization across cortical and subcortical regions, reflecting experience-dependent neuroplasticity. Musicians exhibit enhanced neural responses predominantly in right-hemispheric regions, including the superior temporal gyrus, Heschl's gyrus, insular cortex, inferior frontal gyrus, and auditory midbrain, supporting the specialization of the right auditory cortex for fine pitch processing and tonal working memory (Jantzen et al., 2014). Increased connectivity between the right superior temporal gyrus and

frontal cortex indicates a distributed network for pitch maintenance and comparison (Lu et al., 2022), while heightened activation in the inferior colliculi suggests that superior pitch processing extends to subcortical levels (Bianchi et al., 2017; Bidelman et al., 2011; Parbery-Clark et al., 2009a; Wong et al., 2007).

Voxel-based morphometric studies reveal greater grey matter volumes in musicians within peri-rolandic regions, encompassing primary motor, somatosensory, premotor, anterior superior parietal, and inferior temporal areas. The largest volumes are found in professional musicians compared to amateur musicians or non-musicians (Gaser & Schlaug, 2003). Additional enlargements are observed in the left cerebellum, Heschl's gyrus, and inferior frontal gyrus, along with a larger primary motor cortex, cerebellum, and anterior corpus callosum (Schlaug, 2001). Enhanced activation in auditory association areas (Gaab & Schlaug, 2003), along with the visual cortex, cerebellum, basal ganglia, and supplementary motor area, reflects the multisensory integration required for rhythm, coordination, and musical reading. Furthermore, regions such as the prefrontal cortex, corpus callosum, hippocampus, nucleus accumbens, and amygdala contribute to musicians' superior cognitive, memory, and emotional processing (Levitin & Tirovolas, 2009).

A recent meta-analysis by Criscuolo et al. (2022) further substantiates these cortical and subcortical changes, showing increased grey matter in the superior temporal, postcentral, and medial frontal gyri, hippocampus, insula, thalamus, and left cerebellum, as well as greater white matter in the corpus callosum, internal capsule, and anterior thalamic radiations. Longitudinal studies demonstrate that such neuroplastic adaptations persist even after years without active training, underscoring the effectiveness of music-induced brain changes and adult brain plasticity (White-Schwoch et al., 2013; Herholz & Zatorre, 2012). Professional musicians exhibit

greater activation in auditory association and motor-related regions, with higher grey matter density in the right superior parietal cortex, Heschl's gyrus, and precentral gyrus (Schlaug, 2001; Gaab & Schlaug, 2003). Overall, musicians' brains serve as models to study neuroplasticity (Habib & Besson, 2009; Zatorre & McGill, 2005), demonstrating that musical training enhances auditory, motor, and cognitive processing, supported by increased grey matter in auditory and motor areas (Gaser & Schlaug, 2003; Schneider et al., 2002; Chan et al., 1998; Strait et al., 2009; Zatorre et al., 2007).

In summary, long-term music training drives anatomical and physiological changes in the auditory system. Still, auditory neuroplasticity reflects both innate and learned factors. Mankel and Bidelman (2018) found that 'musical sleepers' who were not trained but had natural musical aptitude showed enhanced neural encoding and speech processing, though trained musicians outperformed them on the SPiN task. The findings highlighted the role of extended practice. Overall, while innate predispositions may contribute, extensive evidence supports the experience-driven nature of plasticity as the basis for musicians' enhanced auditory and cognitive skills.

Different Forms of Music Traditions and their differences

Western and Indian Carnatic music are two distinct yet highly refined musical traditions that have evolved over time. Both exemplify how culture influences the development of musical forms, while their approaches to melody and harmony highlight both similarities and differences. Earlier studies have extensively studied the influence of Western music on different perceptual abilities. Carnatic music is a classical musical tradition of South India. It is one of the oldest musical traditions in the world. It has its roots in ancient Hindu musical traditions and has been developed over thousands of years into a sophisticated and complex musical style. Western music

is a genre created by and reflective of the people who lived and worked across the Western regions of the United States and Canada. There are several crucial differences between Carnatic music and Western music (Mathan School of Music, n.d.).

1. Theory: Carnatic music has a different theoretical foundation than Western music. It is based on ragas (melodic frameworks) and talas (rhythmic frameworks), with an emphasis on improvisation within these structures. Western music, on the other hand, is based on scales, keys, and harmony.

2. Structure: Carnatic music compositions are structured differently from Western music. They are typically structured in a format that includes an introduction, one or more melodic phrases, a faster section called the tānam, and a final section called the sārangi tānam. Western music, on the other hand, is structured into verses and choruses.

3. Improvisation: Improvisation is a crucial aspect of Carnatic music and is highly valued. Musicians are trained to improvise within the framework of a raga, adding their own creative touch to each performance. Western classical music, however, places a greater emphasis on the written score.

4. Notation: Carnatic music notation is different from Western notation. Western notation is a standardized system of symbols used to represent musical pitches and rhythms. Carnatic music notation is called swaralipi and is based on the Indian solfeggio system (Sargam, which uses seven swaras/notes).

5. Instruments: Carnatic music is typically performed on instruments like the veena, violin, mridangam, and ghatam. Western classical music, on the other hand, is typically performed on instruments such as the piano, violin, cello, and flute.

In conclusion, while both Carnatic and Western music are rich and sophisticated musical traditions, they have distinct differences in their theoretical foundations, structures, improvisations, notations, and instruments.

Differences between Hindustani and Carnatic Music forms

Indian music history is divided into three periods: Ancient, Medieval, and Modern. The Ancient period, spanning from the Vedic Age to the 13th century, led to the 14th-century division of Indian music into two distinct traditions: Hindustani and Carnatic, both of which later evolved and flourished independently (Remya, 2022). There are several important distinctions between Hindustani and Carnatic music (Testbook, n.d.), which are listed as follows:

1. Origin: Hindustani music originated in North India, mainly in Uttar Pradesh, Bihar, and Rajasthan, while Carnatic music developed in South India, especially in Karnataka, Andhra Pradesh, Telangana, and Tamil Nadu.
2. Basis: Hindustani music is based on ragas with specific ascending (aroha) and descending (avaroha) scales, whereas Carnatic music has more ragas with fixed structures and decorative melodic movements called gamakas.
3. Rhythmic patterns: Hindustani music uses teental (16 beats), ektaal (12 beats), and jhaptaal (10 beats), while Carnatic music uses adi tala (8 beats), rupaka tala (6 beats), and misra chapu (7 beats).
4. Instruments: Hindustani music features sitar, sarod, tabla, harmonium, flute, and santoor, whereas Carnatic music uses veena, violin, mridangam, ghatam, flute, and kanjira.
5. Performance style: Hindustani music is generally slow, calm, and meditative, while Carnatic music is lively, structured, and rhythmically rich.

6. Format of presentation: A Hindustani performance usually begins with an alap (slow improvisation), followed by jor (medium-paced section), and then the main composition. In Carnatic music, performances typically feature composed pieces, such as varnams, kritis, and ragam-tanam-pallavi, along with guided improvisations.

7. Focus: Hindustani music emphasizes emotional expression and depth, whereas Carnatic music focuses on melody, rhythm, and precision.

To summarize, despite stylistic differences, both Carnatic and Hindustani music share core elements—ragas, swaras, and talas—and promote cultural preservation, cognitive growth, spiritual enrichment, social connection, and lifelong appreciation of Indian classical arts.

Differences between the Effects of Instrumental Music vs. Vocal Music

Vocal music places its main emphasis on singing, performed either solo or in groups, with or without instrumental support. In contrast, instrumental music is produced primarily through instruments and typically lacks lyrics, although it may occasionally include non-articulated vocal sounds. Singers often train with speech-based signals, while instrumentalists focus more on non-speech sounds. Most acoustic instruments are highly linear resonators, meaning their structure dictates playing frequency. Some, however, also involve nonlinear mechanisms that allow for sustained tones—for example, bow-string interaction can generate nonlinear oscillations where pitch depends on string resonance (Schelleng, 1973). The human voice differs: while the vocal tract acts as a linear resonator, pitch control originates from the vocal folds, which must be finely regulated to maintain stability during crescendos (gradual increases in volume) and decrescendos (gradual decreases in volume) in a musical piece.

Kumar and Krishna (2019) compared vocalists, violinists, and non-musicians in terms of their auditory memory and SPiN abilities. Results from digit span tasks and SPiN tasks showed that both groups of musicians performed significantly better than non-musicians on the Backward Digit Span task and SPiN tasks, but not on the Forward Digit Span task. Importantly, singers and violinists performed at similar levels, suggesting that the auditory benefits of music training extend to both vocal and instrumental musicians. Anderson and Kraus (2010) argued that this advantage may stem from musicians' enhanced temporal and spectral encoding of speech, which helps offset the disruptive effects of background noise. The study also found no difference between singers and violinists in speech-in-noise performance, implying that neural adaptations resulting from extensive musical exposure are not strongly influenced by whether the training is vocal or instrumental.

Similar performances of vocalists and violinists were also reported by Kumar et al. (2014) on tests of temporal processing, namely gap detection, dichotic digits, duration patterns, and amplitude modulation of sinusoidally modulated noise. Vocalists performed on par with, or slightly better than, violinists in some measures, though differences were not statistically significant. These results suggest that despite differences in training focus, both vocal and instrumental musicians develop comparable temporal processing and speech perception skills, consistently outperforming non-musicians.

Psychoacoustic Abilities

“Psychoacoustics is the branch of psychophysics involving the scientific study of the perception of sound by the human auditory system” (Psychoacoustics, 2025). The minimum detectable change in frequency that an individual can perceive as different from a reference tone is called the frequency/pitch discrimination threshold.

Similarly, the minimum detectable change in duration that an individual can perceive as different from the reference tone is referred to as the duration discrimination threshold. The minimum detectable gap in the middle of a sound stimulus, which is perceived as a pause in the sound, is referred to as the gap detection threshold. There are various factors that determine an individual's psychoacoustic abilities, with age being one of the most predominant factors.

Effect of Age

Psychophysical studies have demonstrated age-related declines in frequency discrimination (Tao et al., 2023), duration discrimination (Nisha et al., 2022), and gap detection (Fitzgibbons & Gordon-Salant, 1995; Harris et al., 2010; Phillips et al., 1994). Friegang et al. (2011) reported that aging individuals exhibit a decline in central auditory processing abilities, particularly in frequency and duration discrimination. A previous study by Abel et al. (1990) found that older adults exhibited higher difference limens by a factor of 1.8 at 500 Hz and 2.3 at 1000 Hz compared to younger adults. Similarly, Bergeson et al. (2001) observed that older adults showed poorer performance and greater variability in duration discrimination. Additionally, Palmer and Musiek (2014) reported an age-related decline in gap detection thresholds. Kumar and Sangamanatha (2011) conducted a study involving 176 participants aged 20 to 85 years. Temporal processing abilities were assessed using gap detection, duration discrimination, modulation detection, and duration pattern tests. Results showed significantly better performance in individuals aged 20 to 40 years, with deterioration beginning after the fourth decade and accelerating beyond 70 years of age. Thus, based on previous findings, it can be inferred that psychoacoustic abilities begin to decline around the fourth decade of life, with considerable variability observed across individuals.

Effect of Music Training

Musicians demonstrate superior frequency, temporal, and spectral discrimination (McAdams et al., 1999; Micheyl et al., 2006; Rammsayer & Altenmüller, 2006), as well as better speech comprehension in noise and greater sensitivity to prosody (Deguchi et al., 2012; Schön et al., 2004). Electrophysiological studies further confirm that musicians exhibit stronger event-related potentials when processing pitch and musical grammar irregularities (Fujioka et al., 2004, 2005; Koelsch et al., 1999; Pantev et al., 2001; Tervaniemi et al., 2001, 2005).

Several studies have linked these benefits to both peripheral and central auditory mechanisms. Kakar et al. (2021) studied 36 participants (18 musicians and 18 non-musicians) aged 22 to 33 years using difference limen of frequency, psychoacoustic tuning curves, and spontaneous otoacoustic emission tests. Results showed that musicians had a 4- to 5-times better difference limen for frequency scores, sharper psychoacoustic tuning curves, and a greater presence of spontaneous otoacoustic emissions compared to non-musicians. Luiz et al. (2021) examined 30 participants (15 musicians and 15 non-musicians) aged 18 to 27 years using the duration pattern test, the staggered spondaic words test, the masking level difference test, and the dichotic consonant-vowel test. Musicians demonstrated a 3 dB advantage in masking level difference and showed significantly better performance in the other tests as well, compared to non-musicians. Nisha et al. (2022) investigated 60 participants aged 41 to 70 years, divided into three age groups (41 to 50, 51 to 60, and 61 to 70 years), using interaural time difference, interaural level difference, binaural gap detection threshold, and virtual auditory space identification tests. Musicians performed significantly better on all measures, indicating that music training may help delay age-related auditory deterioration. In addition, studies have revealed lower pitch

discrimination thresholds (Spiegel & Watson, 1984), better gap detection (Ishii et al., 2006), and improved temporal resolution in children after 1 to 2 years of music education (Sangamanatha et al., 2012). Other studies have shown that musicians exhibit superior performance in gap detection and pitch discrimination tasks (Barry et al., 2013; Nikjeh et al., 2008; Rammsayer & Altenmüller, 2006). Importantly, Nisha et al. (2022) demonstrated that while aging degraded the performance of non-musicians, musicians maintained strong spatial, temporal, and binaural processing, suggesting that musical training can help preserve auditory skills with age.

SPiN abilities

Speech perception in noise refers to the ability to understand speech when background sounds or noise are present. It is influenced by several factors, including stimulus redundancy, speech rate, background noise, signal-to-noise ratio (SNR), age, language familiarity, and cognitive skills. Older adults tend to have more difficulty understanding speech in noisy environments. The ability to comprehend speech in such conditions depends on several factors, such as an individual's hearing sensitivity, auditory acuity, cognitive abilities (Kiessling et al., 2003; Pichora-Fuller & Singh, 2006), and temporal processing abilities (Anderson et al., 2011; Basire et al., 2025; McFarlane & Sanchez, 2024).

Effect of Age

A study by Bugannim et al. (2025) found that SPiN performance peaked around age 30 and began to decline in the late 30s, paralleling the decline in working memory that started at 38 years. A meta-analysis by Maillard et al. (2023) indicated that musicians performed better than non-musicians, especially at lower SNRs. A recent study by Banumathi et al. (2023) reported a decline in SPiN scores among aging individuals, with the deterioration being more pronounced for syllabic stimuli.

Tremblay et al. (2021) conducted two experiments with 88 participants aged 19 to 87 years. The first examined the SPiN abilities in aging individuals, and secondly, they used magnetic resonance imaging to study SPiN deficits. Results showed an age-related decline in SPiN abilities, with aging linked to diffuse rather than focal dysfunctions. Emami et al. (2023) reported that the negative impact of aging on SPiN abilities outweighs that of hearing loss.

Effect of Music Training on Speech Perception

Yashaswini and Maruthy (2020) investigated how musical training influences the categorical perception of speech and music. They tested 30 trained musicians and 27 non-musicians (aged 20 to 30) on their ability to identify vowels, consonant-vowel syllables, and both vocal and instrumental music notes across 15-step continua. The tests involved identifying consonant-vowel syllables (/da/ to /ga/), vowels (/u/ to /a/), vocal music notes (/ri/ to /ga/), and instrumental music notes (/ri/ to /ga/). Musicians showed categorical perception for both speech and music, whereas non-musicians did so only for speech. These findings suggest that music training extends categorical perception beyond speech, even for stimuli lacking vocal tract features. The authors argued that categorical perception is influenced more by the linguistic relevance shaped through training than by the acoustic or phonetic traits of the stimulus. Since categorical perception underpins speech acquisition (Eimas et al., 1971) and phoneme–grapheme mapping (Mody et al., 1997), the results highlight music’s role in supporting language-related skills.

Moossavi and Gohari (2019) similarly reported that listening to and practicing music fosters long-term plasticity throughout the auditory system, from cochlea to cortex. They suggested that music enhances speech perception because of the functional overlap between speech and music pathways, engaging both perceptual and

cognitive processes. Their findings support the use of music-based interventions to strengthen speech and language functions.

Effect of Music Training on SPiN abilities

Speech perception in noise is particularly challenging because background noise masks rapid spectro-temporal cues essential for optimum speech understanding (Parbery-Clark et al., 2009b). Musicians, through their constant practice, real-time adjustments, and selective attention to instruments in ensembles, seem to develop skills that extend to speech-in-noise processing. Parbery-Clark et al. (2009a) demonstrated, using the SPiN test, that years of musical training were associated with improved frequency discrimination, auditory working memory, and SPiN perception. Similarly, Thomas and Rajalakshmi (2011) reported that musicians recognized speech more accurately, especially at difficult SNRs (0, -5, -10 dB). Abhishek and Rajalakshmi (2013) found that mridangam performers also outperformed the control group on the SPiN test, while Anderson and Kraus (2010) suggested that music-induced brain plasticity strengthens temporal and spectral encoding, buffering against noise.

Meha-Bettison et al. (2018) examined 23 participants (12 musicians and 11 non-musicians) aged 22 to 59 years using the Listening in Spatialized Noise Sentences test and Cortical Auditory Evoked Potentials with babbling noise and /da/ syllable stimuli. The results showed that the N1 amplitude in the non-musician group was drastically reduced at 0 dB SNR, compared to +5 dB SNR in musicians. Electrophysiological studies (Anderson & Kraus, 2010; Parbery-Clark et al., 2009a, 2012; Thomas & Rajalakshmi, 2011; Zubin & Rajalakshmi, 2012) consistently support the role of music training in enhancing speech encoding in the presence of noise. Collectively, these studies suggest that musicianship not only enhances speech understanding in

quiet environments but also provides a clear advantage in complex listening situations, such as those found in ‘cocktail party’ settings.

Working Memory Abilities

“Working memory is an aspect of human memory that permits the maintenance and manipulation of temporary information in the service of goal-directed behaviour” (Hartley & Hitch, 2022). It plays a crucial role in learning, problem-solving, and various cognitive processes. The working memory consists of three components: The central executive is the main system that regulates attention and manages the flow of information among the various components of working memory. The three components include the 1. The phonological loop that processes spoken and written information through the two components: the phonological store, which holds sound-based information, and the articulatory rehearsal system, which enables mental repetition. 2. The visuospatial sketchpad: This component handles visual and spatial information, which is crucial for navigation and object visualization, and 3. The episodic buffer combines information from other components and connects it to long-term memory. Working memory is influenced by various factors, including age, genetics, environmental influences, cognitive load, and emotional state, among others.

Effect of Age

Several studies have indicated deterioration in working memory abilities with aging (Cansino et al., 2020; Monov et al., 2024; Pliatsikas et al., 2019). A recent study compared working memory storage and manipulation across verbal, visuospatial, and tactile modalities in four age groups: 7 to 8, 11 to 12, 25 to 35, and 60 to 69 years. Performance improved until young adulthood and declined in old age in all modalities, with tactile tasks showing the poorest results and visuospatial backward tasks yielding the best performance (Heled & Levi, 2024). In a meta-analysis conducted by Bopp

and Verhaeghen (2005), age-related declines were observed across all verbal span tasks however working memory showed a greater impact of aging compared to short-term memory span tasks. This is because working memory requires both the storage and manipulation of information, whereas short-term memory involves only the temporary storage of information. Grassi and Borella (2013) reported a link between cognitive and psychoacoustic abilities, noting that both decline as individuals age.

Effect of Music Training

Musicians demonstrate enhanced working memory (Chan et al., 1998), auditory stream segregation (Beauvois & Meddis, 1997), auditory attention (Strait et al., 2010), prosody and linguistic processing (Wong & Perrachione, 2007), emotion perception in speech (Strait et al., 2009), and temporal resolution (Monteiro et al., 2010). Beyond auditory skills, musicians often exhibit faster information processing, higher intelligence quotient, stronger problem-solving abilities, and other cognitive advantages (Schellenberg, 2006; Tierney & Kraus, 2013). Benefits also extend to digit span performance (Fujioka et al., 2006) and reading challenging words (Moreno, 2009).

Kumar and Krishna (2019) reported that violinists and singers outperformed non-musicians in auditory memory, echoing earlier evidence of musicians' superior memory (Aizenman et al., 2018; Chan et al., 1998; Ho et al., 2003; Jakobson et al., 2008; Williamson et al., 2010). Interestingly, no group differences appeared in the easier forward digit span test, likely due to its lower difficulty compared to the backward digit span. Such findings highlight neuroplasticity, which is the brain's ability to adapt structurally and functionally through experience, as a mechanism by which music training supports memory.

Other studies suggest that benefits may be task-specific. Suarez et al. (2016) found that while musicians and non-musicians performed similarly on visual memory tasks, musicians excelled in spatial memory, likely due to their experience with reading and interpreting musical notation. Their results indicate improvements in sustained attention, visual-motor synchronization, processing speed, and information organization —abilities directly developed through music performance and sight-reading.

Music's impact also extends into later life. Amer et al. (2013) studied older adults (50 to 77 years) and found that long-term musical training enhanced cognition well into adulthood. Supporting this, Skoe and Kraus (2012) showed that the benefits of early training persist even years after formal practice ends. Broader evidence also suggests overlap between music and bilingualism, as both strengthen cognitive control (Bialystok & DePape, 2009; Krizman et al., 2012) and enhance subcortical auditory processing (Parbery-Clark et al., 2009b; Strait et al., 2013). Neuroimaging studies further reveal that musicians differ from non-musicians in brain regions associated with attention, auditory processing, and motor coordination (Gaser & Schlaug, 2003; Sluming et al., 2002).

Together, these findings demonstrate that music training fosters a wide range of auditory and cognitive abilities across the lifespan, with effects grounded in the brain's remarkable capacity for neuroplasticity.

Effect of Music Training on Auditory Abilities in Children and Young Adults

Jain et al. (2019) investigated whether Carnatic music training affects children's psychoacoustic skills and working memory. Thirty children aged between 10 and 15 years were divided into two groups: those with over three years of music training and those without any training. Psychoacoustical measures included difference limen of

frequency and difference limen of intensity, as well as temporal tasks (gap detection, temporal modulation transfer function, and duration discrimination). Working memory was assessed using the digit span and operation span tasks. Children with music training performed significantly better on tasks involving the difference limen of frequency and the difference limen of intensity, gap detection, and digit span, although no group differences were found for the temporal modulation transfer function or operation span. Similarly, Sangamanatha et al. (2012) reported that after one to two years of training, children showed improvements in temporal resolution tasks except for modulation detection at 200 Hz. Both studies highlight the role of music in fine-tuning the auditory system and enhancing memory in children, while also noting the need for further research to clarify mixed findings.

In adults, Jain et al. (2014) examined the effects of short-term training (8 to 10 sessions) on 10 young adults (18 to 25 years). Tests included gap detection, modulation detection, duration discrimination, frequency and intensity discrimination, duration pattern, and backward masking. Although participants showed improvements across measures, these changes were not statistically significant, contrasting with Flohr's (1981) findings, who reported benefits after 12 weeks of structured training. The authors suggested that further research is needed, particularly in children, to understand how both short-term and long-term training affect psychoacoustical skills.

Effect of Music Training on Auditory Abilities in Older Individuals

Grassi et al. (2017) examined whether lifelong musicianship offsets age-related declines in hearing and cognition. They tested 20 musicians and 20 non-musicians (over 65 years old) on auditory, memory, and higher-order cognitive tasks. While absolute thresholds were similar, musicians outperformed non-musicians on supra-threshold measures such as gap detection, frequency discrimination, and working

memory, suggesting that long-term training supports auditory and cognitive resilience. Earlier studies (Amer et al., 2013; Parbery-Clark et al., 2011) had included younger individuals who were considered “older adults,” but Grassi et al. (2017) focused on those 65 years old and above, highlighting music’s role in delaying aging. Still, the authors noted the need for longitudinal studies to separate the effects of music from other cognitively demanding activities (Ghisletta et al., 2006) and pointed to evidence that even short-term interventions may benefit cognition in dementia.

Skoe and Kraus (2013) studied 770 participants (213 musicians and 557 non-musicians) aged 0.2 to 72.41 years using speech auditory brainstem response/complex auditory brainstem response and observed that functional overshoot occurred between 5 to 14 years of age, with additional overshoots seen at 2 to 5 years and 63 to 70 years, indicating experience-dependent brainstem plasticity in musicians, compared to non-musicians. White-Schwoch et al. (2013) demonstrated that early, moderate music training (4 to 14 years) can even predict faster neural timing to speech in adults aged 55 to 76, even if discontinued for decades. They concluded that childhood exposure leaves lasting imprints on auditory processing. Similarly, Chaddock-Heyman et al. (2021) linked musical training to greater grey matter volume in brain regions supporting executive function, memory, and emotion, suggesting protective effects against age-related decline.

Effect of Music Training on Speech, Language & Education

Musical training is known to enhance auditory, speech, and language skills, particularly with long-term practice (Chandrasekaran et al., 2009). The impact of short-term training, however, is less established. Huotilainen and Tervaniemi (2018) demonstrated that early-life music programs can support auditory development and are particularly beneficial for children with dyslexia, learning or language difficulties,

or hearing impairments. As the field expands, the authors emphasize the pressing need for research to determine which training methods are most effective and who benefits the most from them.

Based on a comprehensive review of psychoacoustic, SPiN, and working memory abilities, as well as the influence of both musical training and aging on these functions, it is hypothesized that musically trained individuals may outperform non-musicians. Furthermore, given the anatomical reorganization, neurogenesis, and physiological enhancement associated with long-term musical experience, it is plausible that individuals with music training may exhibit reduced/delayed age-related declines in behavioral performance, as music training and aging exert opposing effects on these abilities. Therefore, the present study aims to investigate the impact of musical training on aging by evaluating individuals across a continuum of age groups on these parameters.

CHAPTER 3

METHOD

The current study examined psychoacoustic abilities, speech perception in noise (SPiN), and working memory abilities in musicians and non-musicians, ranging in age from 10 to 60, divided into each decade. Furthermore, the study also assessed the relationships among age, psychoacoustic abilities, SPiN, and working memory abilities in musicians and non-musicians.

Research Design and Variables

A cross-sectional between-group design was employed to achieve the study's objectives (Schiavetti & Metz, 2006). The participants were chosen using a purposive sampling technique.

Independent variables of this study were the two categorical variables,

- Age groups (10 to <20, 20 to <30, 30 to <40, 40 to <50, 50 to <60 yrs) and
- Musicianship (Musician and Non-Musician group).

The dependent variables of the study were

- Psychoacoustic measures- Pitch Discrimination Threshold, Duration Discrimination Threshold, and Gap Detection Threshold
- SPiN measures - Percent correct SPiN scores at +5, 0, and -5 dB signal-to-noise ratio (SNR)
- Simple and Complex working memory measures- Backward Digit Span (BDS) scores and Reading Span (RS) scores, respectively.

Ethical Clearance

The study adhered to the 'Ethical guidelines for bio-behavioural research involving human subjects' set by the All India Institute of Speech and Hearing's Ethics Committee (Venkatesan & Basavaraj, 2009). Formal approval for the study was

obtained from the Institutional Ethics Committee prior to the commencement of data collection (Approval No: SH/EC/PhD/AUD-4/2023-2024, dated 22nd September 2023, a copy of which is included in Appendix 1). The purpose and nature of the study were explained to each participant, and written consent was taken.

Participants

The study comprised two primary participant groups: musicians and non-musicians. These groups were defined based on participants' formal training and engagement with music. To examine age-related differences within the two main groups, participants were further categorized into five distinct age brackets. These age groups spanned from young adults to older adults, specifically: 10 to <20, 20 to <30, 30 to <40, 40 to <50, 50 to <60 years. This stratification allowed for a comprehensive analysis of the interaction between age and musical experience on the variables of interest in the study. All the participants (both Musicians and Non-Musicians) were from Mysore city, Karnataka. Using data on the mean and standard deviation (SD) from earlier studies (Jain & Nataraja, 2019; Kakar et al., 2021; Kumar et al., 2016), the appropriate sample size for the study was estimated using G*Power software (version 3.1) (Faul et al., 2009). The effect sizes reported across these studies ranged from 1.17 to 2.98. Sample size estimations were conducted using mean differences between two independent groups, with an α -level of 0.05 and a $(1-\beta)$ level of 0.95. Based on the sample size calculation, a minimum of 15 participants were proposed for each of the 10 sub-groups (i.e., five age groups within each of the two main groups: musicians and non-musicians). However, to account for potential attrition, a total of 181 participants were recruited for the study. Among them, 91 individuals were in the musician group and 90 in the non-musician group, distributed across the specified age ranges. Table 3.1

provides the basic demographic information and the number of participants in each group.

Table 3.1

Number of Male and Female participants along with their mean ages [and one SD] in each age group in the Musician and Non-Musician groups

Age Groups (in years)	Musicians (n)			Non-Musicians (n)			Musicians' Age (Mean, SD)		Non-Musicians' Age (Mean, SD)	
	M	F	Total	M	F	Total	M	F	M	F
10 to <20	8	9	17	10	9	19	16.12, 3.27	16.22, 3.23	17.00, 1.06	18.63, 0.50
20 to <30	11	13	24	9	9	18	24.09, 1.64	24.23, 2.77	25.44, 2.78	22.00, 2.12
30 to <40	7	11	18	8	8	16	34.00, 3.55	33.63, 2.73	34.12, 2.90	36.00, 2.26
40 to <50	7	8	15	7	8	15	42.71, 3.09	44.87, 3.22	43.85, 2.67	45.12, 1.12
50 to <60	8	9	17	13	9	22	55.00, 2.72	54.33, 2.50	53.36, 2.50	55.90, 2.70

NOTE: M-Males, F-Females, mean age, and one SD are in years.

Inclusion Criteria

All the participants met the following inclusion criteria:

- Had hearing thresholds within 15 dB HL at octave frequencies from 250 Hz to 8000 Hz in both ears in individuals aged 10 to <50 years; and hearing thresholds within 25 dB HL at 4000 Hz and 8000 Hz and less than 20 dB HL from 250 Hz to 2000 Hz for individuals in the 50 to <60 age group.
- Showed tympanometry results with a type 'A' or 'As' tympanogram with ipsilateral Middle Ear Muscle Reflex (MEMR) present at normal sensation levels in both ears at 500 and 1000Hz.

- Had Transient Evoked Oto Acoustic Emissions (TEOAEs) to clicks with global SNR and amplitude equal to or greater than 6 dB in both ears.
- Were free from any illness on the day of testing.
- For participants aged 50 to <60 years,
 - obtained a score greater than 24 on the Mini-Mental State Examination (MMSE; Folstein et al., 1975)
 - obtained a score less than 12 on the Screening Checklist for Auditory Processing-Adults (SCAP-A; Vaidyanath & Yathiraj, 2015).
- Were native Kannada speakers
- Had completed at least 10th or 12th grade (excluding the younger age group, 10 to <20 years) education
- Scored above 60 on the World Health Organization Quality of Life Brief (WHOQOL-BREF) (Nakane et al., 2012) questionnaire, indicating a ‘very good’ quality of life.
- Successfully passed the screening with a one-minute noise questionnaire by securing a score below 4, indicating a low risk of noise exposure (Johnson et al., 2017).
- Provided signed written consent indicating their willingness to participate in the study.

Furthermore, the participants in the musician group met the following inclusion criteria.

- Formal music training in Carnatic vocal music for a minimum of five years (in the younger age group, 10 to <20 years) and a minimum of ten years across the other age groups.

- Actively practicing music. ‘Actively practicing music’ was operationally defined as regularly engaging in deliberate and focused efforts to improve one's musical skills and abilities, typically through repetition of specific exercises or pieces, and critical self-reflection. This could involve vocal training, composing, and studying musical theory.
- Primarily one-on-one music-instructed or trained in a small homogeneous group consisting of a maximum of 4 to 5 people.

Participants in the non-musician group had not undergone any formal training in Carnatic music. Additionally, the Mini Profile of Music Perception Skills (Mini-PROMS) (Law & Zentner, 2012; Zentner & Strauss, 2017), a musical assessment tool, and the Edinburgh Lifetime Musical Experience Questionnaire (ELMEQ) (Okely et al., 2021) were administered to both the musician and non-musician groups. Musicians scored significantly higher than non-musicians on both tools across all age groups ($p < 0.01$). Details of the descriptive and inferential statistics for Mini-PROMS and ELMEQ are provided in Tables A1, A2, and Tables A3, A4, respectively, of Appendix 1.

Exclusion Criteria

Participants were excluded from the study based on the following criteria:

- Had a history of middle ear pathology or ear surgery.
- Exhibited neurological/structural ear abnormality, either observed informally or reported during the structured interview.
- Had a positive history or if they were currently diagnosed with hearing loss, ear infections, use of ototoxic medications, exposure to noise, ear surgeries, or speech and language difficulties.
- Were Instrumental musicians or trained Hindustani classical musicians.

Test Environment

All audiological examinations were conducted in a quiet setting with adequate lighting and ventilation. A ‘quiet setting’ for a hearing test refers to an environment with low background noise levels (< 50 dB A). All tests were conducted using supra-aural headphones with good ambient noise attenuation.

Instrumentation, Materials, and Software

- The absolute threshold test was administered to determine hearing thresholds using the Maximum Likelihood Procedure (MLP) (Grassi & Soranzo, 2009) through MATLAB (version R 2014a) software installed in a HP laptop.
- A calibrated Titan (Interacoustics, Denmark, 2013) immittance instrument was used for tympanometry and MEMR testing.
- A calibrated Otodynamics Echoport 292 II dual probe system with ILO v6 data management and analysis software (Otodynamics Ltd, London, United Kingdom, 2015) was used to record and analyse the TEOAEs.
- A Hewlett-Packard personal laptop with a 10th Gen Intel i3 Core processor and a 64-bit operating system was used for all the tests and analysis.
- The stimuli for the auditory tasks were calibrated before administering the tests and routed via Sennheiser HD-569 headphones (Sonova Holding AG, Denmark, Germany, 2016). These headphones provided the stimulus for all psychoacoustic, SPiN, and working memory tests.
- Larson and Davis 831C Sound Advisor Sound Level Meter (Larson Davis Inc., NY, USA) and AEC201-A- ear simulator, suitable for Sennheiser HD 569 headphones, were used for the calibration of the stimulus.

- MATLAB version R 2014a software (Mathworks Inc., Natick, Massachusetts, USA, 2014) installed in a HP laptop was used to administer the psychoacoustic tests, which utilized MLP to determine the thresholds.
- MATLAB version R 2014a software (Mathworks Inc., Natick, Massachusetts, USA, 2014) installed on a HP laptop (Intel i3 processor, 64 GB RAM) was used to digitally mix the recorded audio stimulus with noise to generate stimuli for the SPiN test.
- All working memory tests were conducted using Smriti-Shravan, an institutional program that included an auditory-cognitive training module (Kumar & Sandeep, 2013), on the HP laptop delivered through Sennheiser HD-569 headphones.
- Statistical Package for Social Sciences Version 26 (IBM corporation, New York, USA, 2018) and GraphPad Prism version 9 (GraphPad software, Boston, 2020) were used for statistical analyses and generating figures for the study, respectively.
- MMSE was used to assess and screen for cognitive impairment in older adults. It assessed cognitive function in five domains: orientation, registration, attention and calculation, recall, and language and praxis.
- SCAP-A was administered to rule out auditory processing disorders in older adults who had normal hearing. It consisted of two questionnaires: one for older adults and the other for their family members.
- An online musical test battery called 'Mini-PROMS' was used to assess the musical skills objectively across four different modalities, namely Melody, Metric Accent, Tempo, and Tuning.
- ELMEQ was used to assess the participants' musical experiences and engagement throughout their lives. The questionnaire consisted of four sections, namely Musical Instruments, Singing, Reading Musical Notation, and Listening to Music.

- The WHOQOL-BREF (Nakane et al., 2012) scale was administered to assess the quality of life of all the participants across four areas of life, namely Physical Health, Psychological, Social relationships, and Environment.
- The One-Minute Noise Questionnaire, a brief screening tool designed to rapidly evaluate an individual's risk of noise-induced hearing loss, was utilized for the assessment.
- G*Power version 3.1.9.4 software (Heinrich Heine University, Denmark, 2019) was employed to estimate the sample size for the current study.
- Mendeley reference manager version 2.138.0 (Netherlands, UK, 2025) (a proprietary software) was used for reference management.

Procedure

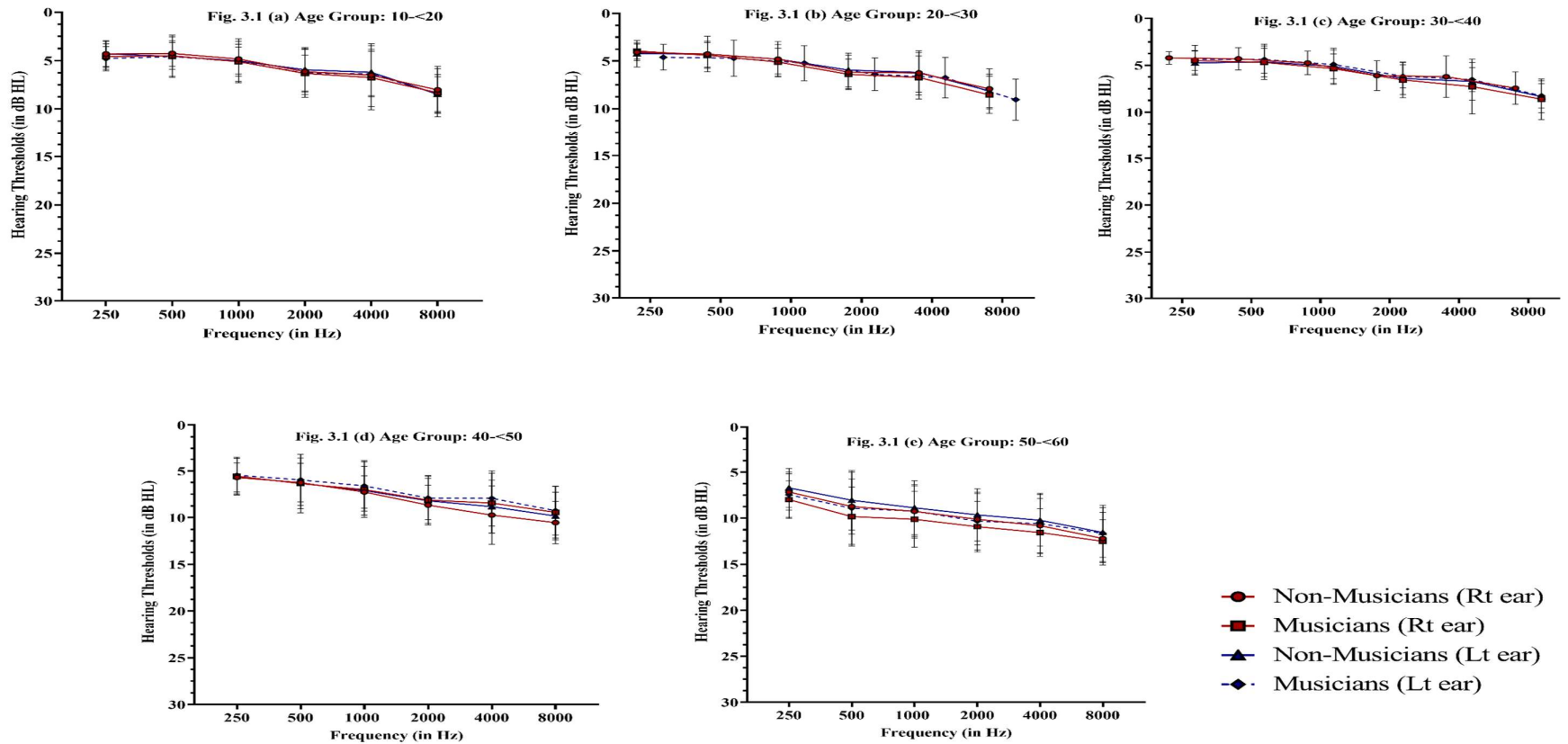
A brief case history was gathered initially. MMSE and SCAP-A were administered subsequently to the older adult age group (50 to <60 years) to determine their eligibility for inclusion in the study.

Audiological assessment

Basic audiological measures, including pure tone threshold estimation, Tympanometry, MEMR, and TEOAE tests, were carried out on all participants. Figures 3.1(a-e) depict the Mean and one SD values of pure tone thresholds in musicians and non-musicians in both right and left ears in 10 to <20, 20 to <30, 30 to <40, 40 to <50, and 50 to <60 age groups, respectively. Figures 3.2 (a-b) show the mean and one SD values of global TEOAE amplitudes across different age groups in musician and non-musician groups for the right and left ears, respectively.

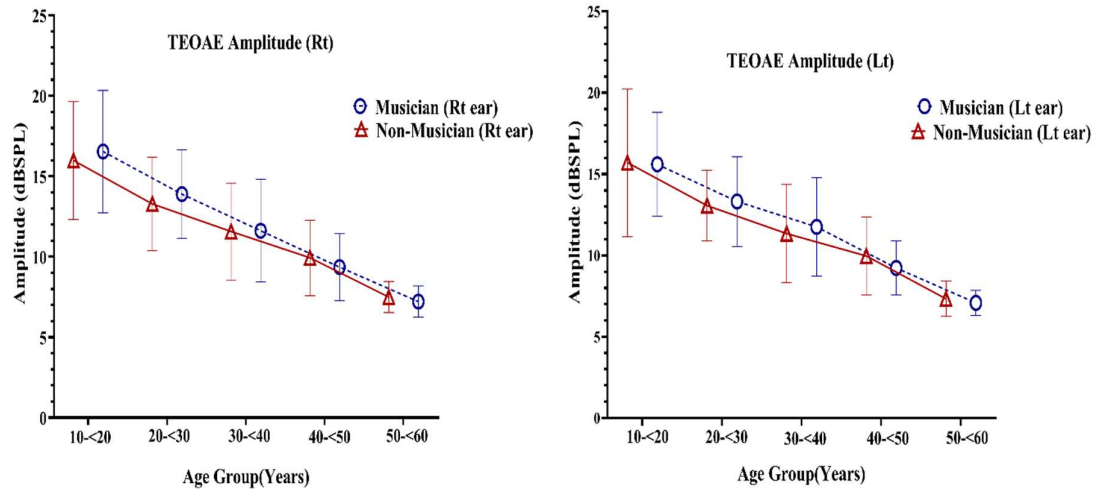
Figures 3.1 (a), 3.1 (b), 3.1 (c), 3.1 (d), and 3.1 (e)

Panel showing the Mean and one SD (error bars) of pure tone thresholds for Musicians and Non-musicians for the right and left ears across five different age groups.



Figures 3.2 (a) and 3.2 (b)

Mean and one SD values (error bars) of TEOAE amplitudes (in dB SPL) for Musicians and Non-Musicians across different age groups for the right and left ears.



Shapiro-Wilk's test of normality revealed non-normal distribution of pure tone hearing thresholds and TEOAE amplitudes in some of the age groups. Hence, the Mann-Whitney U tests (with Bonferroni's corrections) were used to assess the significance of differences between musicians and non-musicians in pure tone thresholds and TEOAE amplitudes. Results revealed no significant differences in pure tone thresholds and TEOAE amplitudes between musicians and non-musicians in all age groups ($p > 0.05$). The mean and one SD values for pure tone thresholds and TEOAE amplitudes are given in Tables A5 and A6, respectively, of Appendix 1.

The WHOQOL-BREF scale administered to both groups showed that all participants reported a 'very good' quality of life. The Mann-Whitney U test showed there were no significant differences in the quality of life between musicians and non-musicians. The mean and SD values of the WHOQOL-BREF mean scores and the results of the Mann-Whitney U tests are given in Tables A7 and A8, respectively, of

Appendix 1. Overall, the participants in both musician and non-musician groups did not differ in terms of hearing thresholds, acoustic reflex thresholds, TEAOE amplitudes, and quality of life. Additionally, participants in the musician groups achieved significantly better scores on the Mini-PROMS and ELMEQ.

To evaluate the study's objectives, psychoacoustic, SPiN, and working memory tests were administered. To minimize the Order Effect, the psychoacoustic, SPiN, and working memory-based tests were randomized and presented to the subjects through a counterbalancing procedure. The procedure for each test has been explained in detail in the following sections.

Psychoacoustic Tests

Three tests were conducted to assess psychoacoustic abilities: the Pitch Discrimination Test, Duration Discrimination Test, and Gap Detection Test. All tests were administered using the MLP toolbox implemented in the MATLAB software (Grassi & Soranzo, 2009). In MLP, the psychometric function that maximizes the likelihood of eliciting the response is presented as the subsequent stimulus, thereby increasing the likelihood of reaching the threshold with fewer trials.

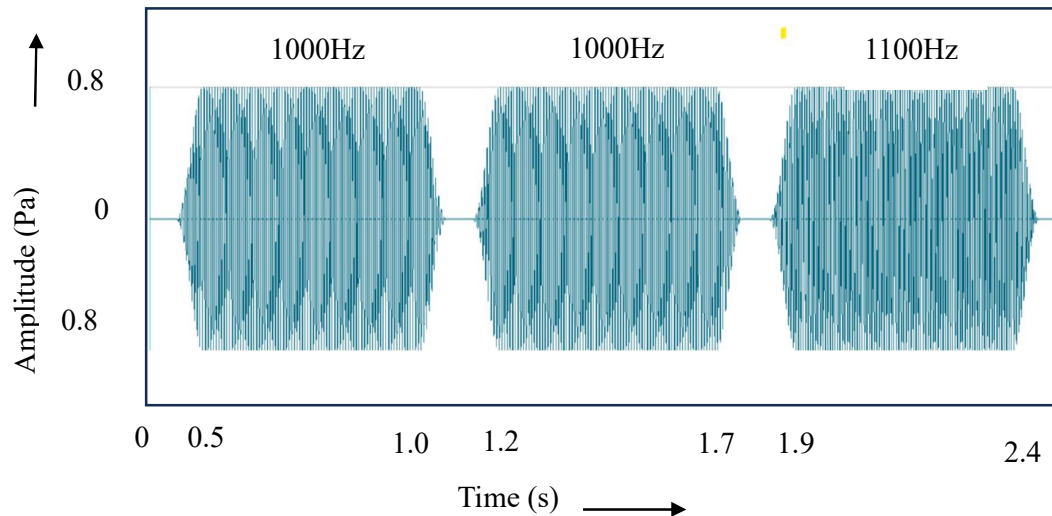
The test stimuli were presented binaurally through high-fidelity headphones, and participants' responses were recorded. All the tests were presented at an intensity level of 70 dB SPL. The output of the headphone was calibrated using a Larson Davis 831C Sound Advisor Sound Level Meter (Larson Davis Inc., NY, USA) connected to an AEC201-A ear simulator. Each test consisted of 30 trials. All the psychoacoustic tests were performed using a three-interval alternate forced-choice technique to track a 79.4% correct response criterion on the psychometric function. Participants were required to identify the interval containing a variable acoustic feature. Each test is described in the following sections.

Pitch Discrimination Test. Also known as the frequency discrimination test, it assesses an individual's ability to perceive differences in sound pitch (frequency). The test is administered to assess the participant's frequency resolution ability, which is critical for speech perception (Arzounian & De Cheveigné, 2016).

Stimulus. This measure, also known as the Frequency Difference Limen, assesses the smallest detectable change in frequency between two successive steady tones. It is assessed using a 1000 Hz pure tone as the standard stimulus. The stimulus was presented binaurally at 70 dB SPL. Each trial consisted of three sound intervals: one of the sound intervals contained a pure tone with a variable frequency, which was always higher than the standard frequency. The other two intervals contained pure tones at a fixed standard frequency. The stimuli consisted of pure tones with a duration of 250 ms. Both the standard and variable stimuli featured a 10-ms raised cosine ramp at the beginning and end (Grassi & Soranzo, 2009). The frequency deviation of the variable stimulus ranged from a minimum of 0.1 Hz to a maximum of 100.1 Hz. Figure 3.3 presents a graphical representation of the pitch discrimination test stimulus used in this study.

Figure 3.3

A graphical representation of the pitch discrimination test stimulus illustrating three sound intervals, each consisting of two relatively low-pitched tones and one relatively high-pitched tone.



Procedure. Each test session consisted of 30 trials, during which participants were required to identify the variable sound interval among the three sound intervals presented. They were instructed as follows: “You will hear three blocks of sounds. All three will contain tones, but one of the tones will have a different pitch compared to the other two. Your task is to identify the tone with the variable/higher pitch compared to the other two.” The smallest detectable frequency difference was assessed to determine an individual's ability to distinguish between two closely spaced frequencies. MLP was utilized to minimize the number of trials required to converge on the threshold. The threshold thus obtained was referred to as the Pitch Discrimination Threshold. The frequency difference corresponding to the 79.4% point of the psychometric function was determined.

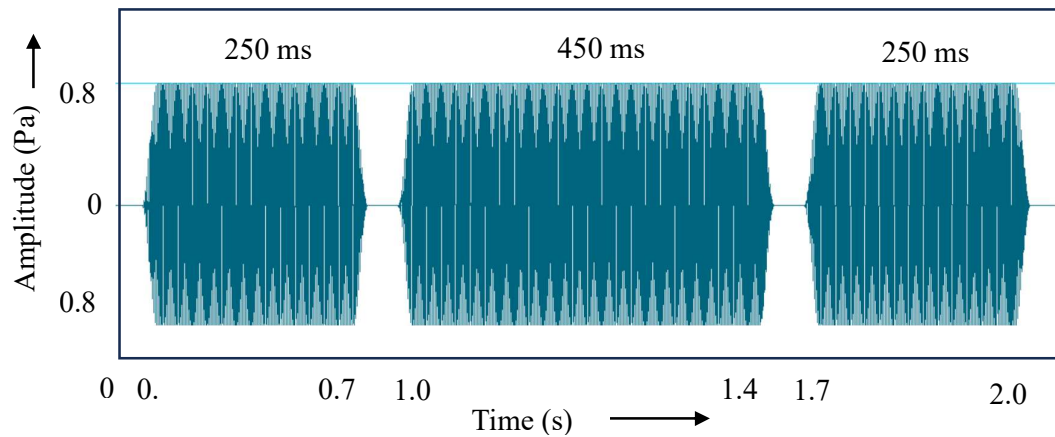
Duration Discrimination Test. The Duration Discrimination Test assesses an individual's ability to detect differences in the length or duration of sequentially presented sounds. Duration discrimination abilities are fundamental for optimum speech perception (Bergeson et al., 2001; Schneider, 1997; Stuart & Phillips, 1996).

Stimulus. The duration discrimination threshold was measured using a 1000 Hz pure tone with an anchor duration of 250 ms (Abel, 1972; Phillips et al., 1994), as described by Kumar and Sangamanatha (2011). The tone included 10-ms raised cosine

onset and offset gates and was presented binaurally at 70 dB SPL. The duration deviation ranged from 0.1 ms to 200.1 ms. The test consisted of 30 trials. Figure 3.4 depicts the graphical representation of the duration discrimination test stimulus used in the current study.

Figure 3.4

A graphical representation of the duration discrimination test stimulus, featuring three sound intervals consisting of two short durations and one relatively longer duration.



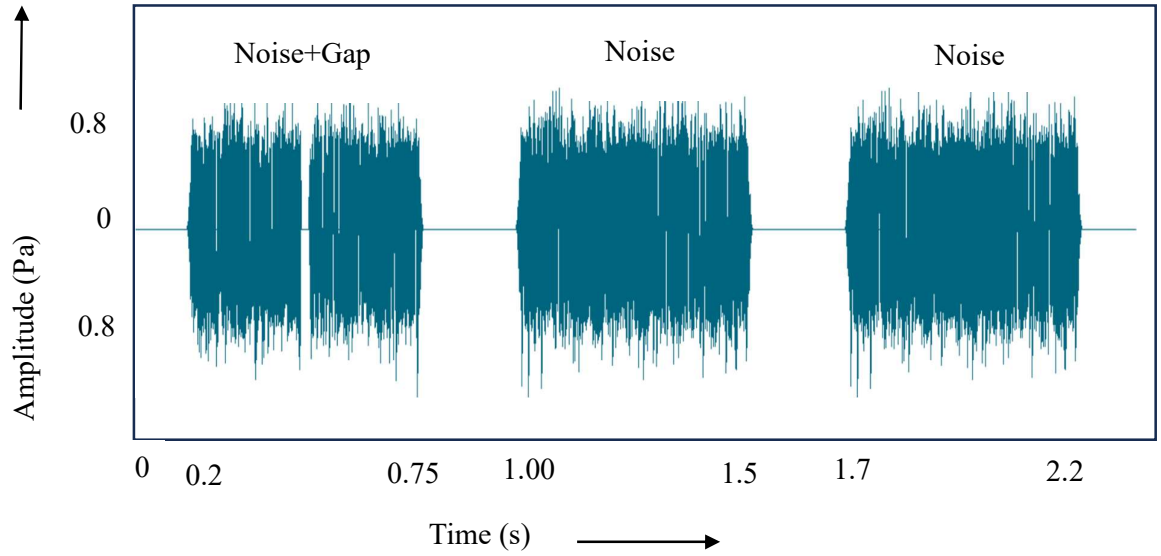
Procedure. Each trial consisted of three sound intervals, two of which had pure tones with a standard duration of 250 ms, while the third interval contained a pure tone with an adjustable duration that was longer than the standard by a range of 0.1 to 200.1 ms. They were instructed as follows: “You will hear three blocks of sounds. All three will contain tones, but one of the tones will have a longer duration compared to the other two. Your task is to identify the tone with the longer duration compared to the other two.” The minimum duration difference corresponding to the 79.4% point of the psychometric function was noted down.

Gap Detection Test. The Gap Detection Test is a psychoacoustic measure used to assess an individual's ability to detect brief silent intervals (gaps) within an ongoing sound. Gap detection is essential for speech perception, as it enables individuals to recognize and differentiate speech sounds that change quickly over time (Mori et al., 2015; Phillips, 1999).

Stimulus. This test assessed the participant's ability to detect a temporal gap within a 500-ms wideband noise stimulus (Harris et al., 2010). Unlike tones, the amplitude distribution of noise remains unchanged when a gap is introduced, making noise more suitable for the gap detection test. In contrast, clicks may be audible when gaps are inserted between tones (Moore, 2003). The broadband noise of 500 ms duration contained 0.5 ms cosine ramps at the start and end of the gap to prevent sudden shifts in the frequency spectrum, which could otherwise help participants detect the gap. The minimum and maximum gap lengths ranged from 0.1 ms to 64 ms, and the stimulus was presented binaurally at 70 dB SPL. Figure 3.5 provides a graphical representation of the gap detection test stimulus used in this study.

Figure 3.5

A graphical representation of the gap detection test stimulus, consisting of three sound intervals, consisting of two continuous noise intervals and one noise interval with a gap



Procedure. The test consisted of 30 trials. Each trial presented three stimulus intervals, two of which contained a standard 500 ms broadband noise, while the other interval featured a variable noise containing a gap. They were instructed as follows: “You will hear three blocks of sounds. All three will contain noise, but one of them will have a gap within the noise. Your task is to identify the block that contains the gap.” The Gap Detection Threshold was determined as the 79.4% point on the psychometric function, which was noted down.

Speech Perception in Noise Test

The SPiN test is used to evaluate an individual's ability to recognize and understand speech in the presence of background noise. It assesses auditory processing abilities in challenging listening situations.

Stimulus. The SPiN test was assessed using recorded sentences from the Kannada Sentence Identification Test (Geetha et al., 2014). This test consisted of 25 homogeneous lists. From these, the first six lists were selected and used in the current experiment. Each list contained ten sentences, and each sentence included four key words. The six lists used in the present study are provided in Appendix 1. These

sentences were mixed with the four-talker speech babble (Basavanahalli Jagadeesh & Kumar, 2019, 2021a, 2021 b). The sentences and four-talker babble were mixed using a custom MATLAB script (Gnanateja, 2017) to obtain SNRs of +5, 0, and -5 dB. The sentences were mixed with random portions of the babble. The desired SNR was achieved by adjusting the babble amplitude while maintaining a constant speech amplitude. The noise started 500 ms before and continued 500 ms after the target sentence. The stimulus was presented at 70 dB SPL binaurally.

Procedure. Participants were evaluated at +5 dB, 0 dB, and -5 dB SNR levels, with two lists presented per SNR level. Before testing, the procedure was explained, and participants were seated comfortably in a quiet room setting. They were instructed as follows: “You will hear sentences embedded in noise through these headphones. Some will be easy to hear and understand, while others may be more challenging. Each time, you must listen carefully and repeat everything you hear, even if you need to infer words from context or only catch parts of the sentence.”

Responses and Analysis. The subject's responses were recorded on response sheets and also audio-recorded for subsequent analysis. For each time a correct keyword was repeated, a score of 1 was awarded, and a score of 0 for wrong or partially accurate repetitions. The number of correct repetitions of words in the two 10-sentence lists was converted to percent correct scores for each SNR (average of scores for the two sentence lists presented).

Auditory Cognitive/ Working Memory-Based Tests

Participants' working memory was assessed using two tasks: the Backward Digit Span Test and the Reading Span Test. Both tests were administered using Smriti-Shravan, an in-house software developed for assessing working memory (Kumar et al., 2013). The software was installed on a personal HP laptop, and the tests were

administered through high-quality Sennheiser HD 569 headphones. The validation procedures for these tests were described in detail by Basavanahalli Jagadeesh and Kumar (2019).

Backward Digit Span Test. The 'Audio-Backward Span' module of the Smriti-Shravan software was used to assess the BDS ability. The test utilized eight digitally recorded numbers in Kannada (ranging from 1 to 8, excluding 2), presented binaurally at an intensity of 70 dB SPL. Participants were instructed to type the digits in the reverse order in which they were presented. They were instructed as follows: “You will hear a sequence of digits that you need to remember. Once the trial ends, you will be asked to enter or select the digits in reverse order.” Prior to the main test, a practice trial with immediate feedback was administered to familiarize participants with the task. Once they were comfortable with the procedure, the main test commenced using a one-up-one-down psychophysical adaptive method to estimate digit span. The test began with the presentation of a two-digit sequence. Digits were presented binaurally with an inter-stimulus interval of 1 second. Each correct response increased the number of digits presented in the next series by one. An incorrect response resulted in a decrease of one item in the subsequent series. This procedure was repeated for six reversals. The backward spans were calculated as the mean span of the last four reversal points.

Reading Span Test. The Reading Span Task was designed to evaluate participants' working memory by assessing their ability to recall target stimuli (primary task) while simultaneously processing an interfering secondary task. In each trial, participants were presented with a statement, followed by a consonant-vowel (CV) syllable (e.g., Naukaranige varṣaḍalli eradu ba:ri ma:ṭra katṣe:rige ho:galu anumati ni:ḍala:guttade followed by /tʃa:ku/). The statements were either meaningful

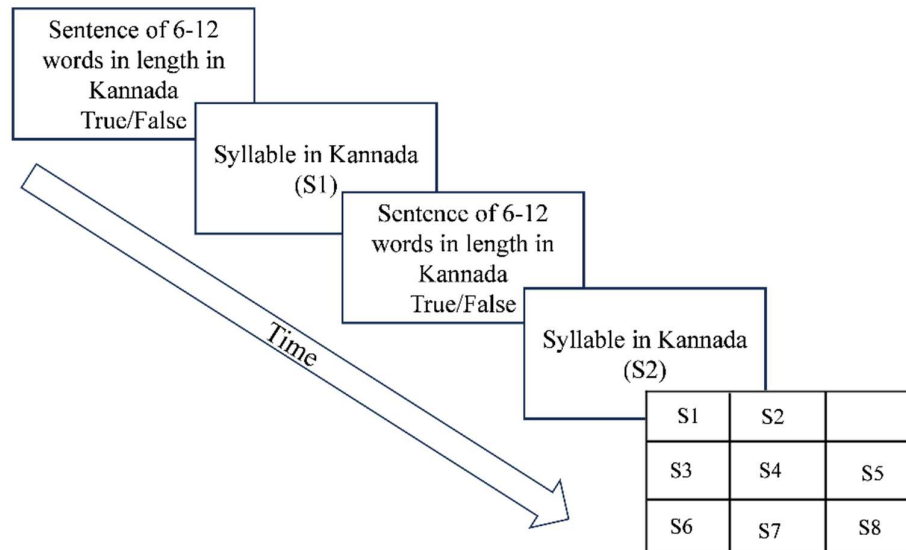
or illogical, and participants were required to judge the meaningfulness of each statement while remembering the CV syllable that followed. Half of the statements were meaningful and half were illogical, presented in a randomized order. Participants were not informed of the ratio or sequence of statement types. An example set of stimuli from the Reading Span Task is illustrated in Figure 3.6. After the participant responded to the presented statement (or after 30 seconds elapsed, whichever occurred first), a CV syllable was displayed on the screen for 3 seconds. The participant was instructed to remember the syllable for later recall. Each trial consisted of a sequence of such elements, with each element comprising one secondary task (judgment of meaningfulness of the sentence) followed by one primary task (memorization of the syllable). Once all elements in each trial were completed, a response screen appeared, displaying a grid containing multiple CV syllables. Participants were required to select the syllables they had seen in the same order of presentation. The number of elements within each trial varied randomly between three and six, thereby preventing the participant from anticipating the memory load. The subjects were instructed as follows: “You will see a sentence on the screen, which may be either correct or incorrect. If the sentence makes sense, click/ say ‘True;’ otherwise, ‘False.’ After each sentence, a word will be shown that you need to remember. Different sentence and word pairs will be repeated several times. Try to respond accurately to each sentence and remember the words in the correct order. At the end, you will be asked to select the words from a list. Try to select the words in the same order as they were presented.”

Performance accuracy was recorded for both the primary (syllable recall) and secondary (sentence judgment) tasks. Participants were required to maintain a minimum of 85% accuracy on the secondary task to ensure sufficient engagement

(Sanchez et al., 2010). The reading span score was quantified using a partial credit scoring method, which weighted the proportion of correctly recalled words, irrespective of their order of recall. This measure sums the correctly recalled elements, without considering perfect recall or serial order within items (Conway et al., 2005). The weighted score ensured that each word carried equal importance and that recalled words received a score of one, while unrecalled words received a score of zero. Figure 3.6 illustrates the stimulus used for the reading span test.

Figure 3.6

An example of a stimulus used in the reading span test



Test-Retest Reliability

To assess test-retest reliability, approximately 10% of the sample size (minimum $N = 20$) underwent reassessment of the entire test battery three months after the initial test administration. The reassessment was conducted for the psychoacoustic, SPiN, and working memory tests. The Intra-class Correlation Coefficient method was employed to assess the test-retest reliability of these measures. Intra-class Correlation Coefficient values were interpreted as indicating

‘poor’ reliability (<0.5), ‘moderate’ reliability ($0.5–0.75$), ‘good’ reliability ($0.75–0.9$), and ‘excellent’ reliability (>0.9) (Koo & Li, 2016).

Statistical Analyses

The statistical analysis was conducted using Statistical Package for Social Sciences software, version 26.0 (IBM Corp, New York, USA, 2018). The Shapiro-Wilk test was used to assess the normality of the data distribution. If the data followed a normal distribution, parametric tests were applied. When the data did not follow a normal distribution, various transformations, namely logarithmic, square, square root, arcsine, and rationalized arcsine, were applied to achieve normality. If the data remained non-normal even after transformation, non-parametric tests were employed for analysis.

For one-way ANOVA, effect size was interpreted using the following criteria: ($\eta^2 = 0.01–<0.06$) as ‘small’, ($\eta^2 = >0.06–<0.14$) as ‘moderate’, and ($\eta^2 = >0.14$) as ‘large’ (Cohen, 2013). Effect sizes for t-tests were calculated using Cohen’s d [$d = (\mu_1 - \mu_2)/\sigma$], defined as ‘small’ (0.2), ‘medium’ (0.5), and ‘large’ (0.8) (Cohen, 2013). For non-parametric tests, the correlation coefficient (r) was computed as the Z value divided by the square root of the sample size [$r = Z/\sqrt{N}$]. Interpretation of ‘ r ’ values was as ‘small’ effect ($0.1–<0.3$), ‘medium’ effect ($0.3–<0.5$), and ‘large’ effect (≥ 0.5) (Cohen, 2009). Post-hoc analysis was conducted using Bonferroni’s correction. The results obtained with False Discovery Rate correction were comparable; therefore, the Bonferroni-corrected results were reported. Table 3.2 indicates the effects studied, the dependent variables employed under different study objectives, and the Parametric or Non-Parametric tests used.

Table 3.2

Effects studied and the Statistical tests used to achieve the objectives of the study.

Effects studied	Dependent Variables Studied	Parametric Test	Non-Parametric Test
Objective 1			
Main Effects across the subject factors 1. Age 2. Musicianship	• PDT • DDT • GDT	• 2-way ANOVA • 1-way ANOVA to assess the age effect • Independent t-test to assess the musicianship effect • Post-hoc analysis with Bonferroni's corrections	Nil
The interaction effect between the subject factors Age* Musicianship	• PDT • DDT • GDT	• Post-hoc analysis with Bonferroni's corrections	
Objective 2			
Main Effects across the subject factors 1. Age 2. Musicianship	• Percent Correct SPiN scores at a. +5 b. 0 c. -5 dB SNRs		• Kruskal-Wallis for each SNR in musicians and non-musicians to assess age effects • Post-hoc analyses using the Mann-Whitney U Tests for each SNR to assess age and musicianship effects
Objective 3			
Main Effects across the subject factors 1. Age 2. Musicianship	BDS	• 2-way ANOVA • 1-way ANOVA to assess the age effect • Independent t-test to assess the musicianship effect • Post-hoc analysis with Bonferroni's corrections	Nil
The interaction effect between the subject factors Age* Musicianship	BDS	• Post-hoc analysis with Bonferroni's corrections	
Main Effect across the subject factors 1. Age 2. Musicianship	RS		• Kruskal-Wallis Test (in Musicians and Non-musicians) • Two sets of post-hoc analyses using the Mann-Whitney U-Test to assess age and musicianship effects
Objective 4			
Correlation between age, psychoacoustic, SPiN, and working memory abilities	• PDT • DDT • GDT • Percent correct SPiN scores at +5, 0 and -5 dB SNRs • BDS • RS • Age		Non-parametric Principal Component Analysis (PCA) separately conducted for Musicians and Non-Musicians

CHAPTER 4

RESULTS

The current study aimed to assess the age-related changes in psychoacoustic abilities, speech perception in noise (SPiN), and working memory abilities in musicians and non-musicians. This study also compared the psychoacoustic, SPiN, and working memory abilities between musicians and non-musicians in each age group. Furthermore, the study examined the relationship among age, psychoacoustic abilities, SPiN, and working memory abilities in musicians and non-musicians. A total of 181 participants ($N = 181$) across five age continua (10 to <20, 20 to <30, 30 to <40, 40 to <50, and 50 to <60) participated in the study. The participants included 91 Musicians and 90 Non-musicians. Musicians were vocally trained in Carnatic classical music for a minimum of 5 years (in the 10 to <20 year age group) and 10 years (in other age groups). To explain the results, individuals between the ages of 10 and <30 are operationally classified as ‘young,’ those between the ages of 30 and <50 as ‘middle-aged,’ and those aged 50 and above as ‘older adults.’

Objective 1: Psychoacoustic abilities

a. Pitch Discrimination Test

Figure 4.1 represents the Mean and one Standard Deviation (SD) values of Pitch Discrimination Thresholds (PDTs) for both musician and non-musician groups across different ages. Since PDT values in some age groups were not normally distributed, square root transformations were applied to the data. The results of Shapiro-Wilk’s test of normality across the five age groups for all the dependent variables are given in Tables A9 to A13 of Appendix 2. Following the transformation, most of the data (9

out of 10) followed a normal distribution, as indicated by the Shapiro-Wilk normality test. Hence, all statistical analyses were performed on the transformed data; however, the original unit of measurement was used for graphical representation.

Figure 4.1

Mean and one SD (error bars) of PDT values across different age groups in Musicians and Non-Musicians. Individual data points are also shown in the figure.

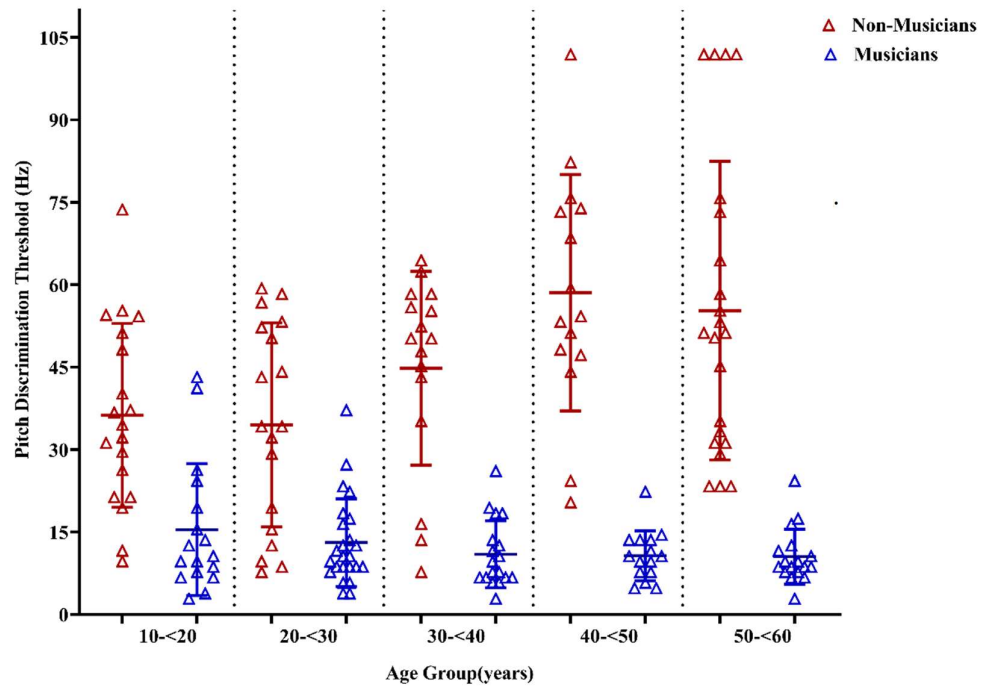


Figure 4.1 illustrates that the mean PDT values of musicians were better than those of non-musicians on pitch discrimination tasks across all age groups, with the difference being more pronounced in the middle-aged and older groups.

Additionally, the variability of the PDT, as measured by SD and individual data points, was higher in the non-musician group compared to the musician group. Two-way Analysis of variance (ANOVA) on PDT with musicianship and age groups as the between-subject factors indicated a significant main effect of musicianship

[$F(1,171)=250.676$, $p<0.001$, $\eta^2p=0.594$] and a significant interaction between musicianship and age [$F(4,171)=5.154$, $p<0.001$, $\eta^2p=0.108$]. However, age had no significant effect. The interaction effect is attributable to a more pronounced difference in PDT between musicians and non-musicians in the older age groups.

As a significant interaction was found between musicianship and age, follow-up one-way ANOVAs were conducted separately for musicians and non-musicians, with age groups as the between-subjects factor. Results showed a significant main effect of age in non-musicians [$F(4,85)=4.579$, $p=0.002$, $\eta^2p=0.177$] but not in musicians. The effect size was 0.177 (indicated by partial eta squared, η^2p), suggesting a large age effect in non-musicians. Follow-up post hoc pair-wise comparisons with Bonferroni's corrections showed that non-musicians in the 40 to <50 and 50 to < 60 year age groups had significantly poorer PDTs compared to younger age groups. The summary of the results of pair-wise comparisons across age groups in non-musicians is given in Table 4.1. Details of post-hoc test results with Bonferroni's correction applied to the p-value are given in Table A14 of Appendix 2.

Independent sample t-tests with Bonferroni's corrections were carried out between musicians and non-musicians within each age group to assess the effects of music training. The results showed that musicians exhibited significantly better pitch discrimination abilities than non-musicians in each age group ($p < 0.05$). The effect size (Cohen's d) varied from 1.524 to 3.740, implying a large musicianship effect. The results of the independent t-tests are presented in Table 4.2.

Table 4.1

Summary of the results of pair-wise comparisons in Non-Musicians across different age groups on the pitch discrimination test

Age in years	10 to <20	20 to <30	30 to <40	40 to <50
20 to <30	NS			
30 to <40	NS	NS		
40 to <50	S	S	NS	
50 to <60	NS	S	NS	NS

Note. NS- Not Significant, S- Significant at 0.005 level (adjusted for Bonferroni's multiple comparisons)

Table 4.2

Results of Independent t-tests comparing Musicians and Non-Musicians within each age group on the pitch discrimination test

Groups	Age Groups (in years)	t	df	Corrected p
Musicians and non-musicians	10 to <20	4.566	34	<0.005**
	20 to <30	5.000	40	<0.005**
	30 to <40	7.606	32	<0.005**
	40 to <50	10.242	28	<0.005**
	50 to <60	8.762	37	<0.005**

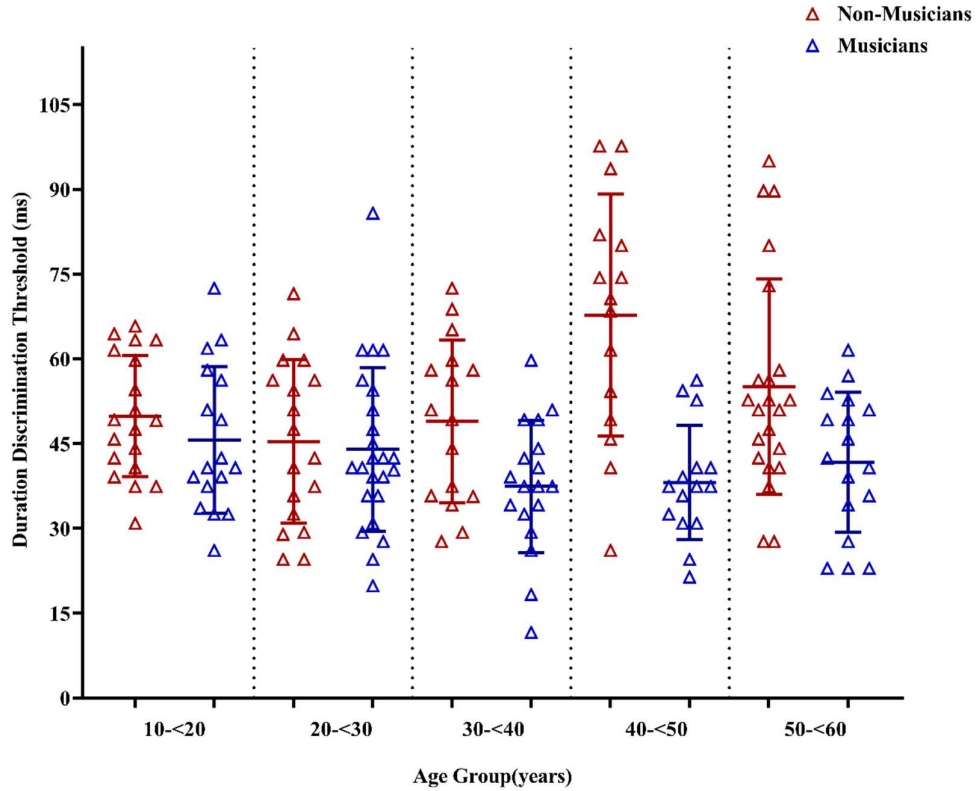
Note. t-test statistic, df-degrees of freedom, p-significance level. Corrected p-value= (obtained p-value)*(number of pairwise comparisons made). **-sig. at 0.01.

b. Duration Discrimination Test

Figure 4.2 shows the Mean and one SD of Duration Discrimination Thresholds (DDTs) for both groups across different ages. The results of Shapiro-Wilk's test of normality are given in Tables A9 to A13 of Appendix 2. Since data showed non-normal distribution in some age groups, square root transformations were applied to the data. The square root transformation yielded normality in all age groups; therefore, the transformed values were used for statistical analysis.

Figure 4.2

Mean and one SD (error bars) of DDTs across different age groups in Musicians and Non-Musicians. Individual data points are also shown in the figure.



It can be seen from Figure 4.2 that musicians had better mean DDT values than non-musicians in the middle and older age groups. Deterioration in performance was evident in non-musicians, especially in the 40 to < 50-year-old age range. A two-way ANOVA with musicianship and age groups as the between-subject factors indicated a significant main effect of musicianship [$F(1,171)=28.663$, $p<0.001$, $\eta^2p=0.144$] and interaction effect of musicianship and age [$F(4,171)=4.029$, $p=0.004$, $\eta^2p=0.086$]. There was no significant age effect. A significant interaction between age and musicianship indicates that the advantage of musical training on DDT varied across different age groups. A one-way ANOVA was

conducted separately for musicians and non-musicians, with age groups as the between-subjects factor, to further examine the interaction effect. The results revealed a significant main effect of age on DDTs in the non-musician group [$F(4,85) = 4.050$, $p = 0.005$, $\eta^2p = 0.160$], but not in the musician group. The effect size (η^2p) was 0.160, demonstrating a large age effect in non-musicians. Given the presence of age effects in non-musicians, pair-wise comparisons (with Bonferroni's corrections for multiple comparisons) were examined to evaluate the age effects further. The summary of the results of the pair-wise comparisons across different age groups on DDT in non-musicians is shown in Table 4.3. DDTs were significantly affected in non-musicians within the 40- to <50-year age group. Details of post-hoc test results with Bonferroni's corrections applied to the p-value are given in Table A15 of Appendix 2.

The DDTs were compared between musicians and non-musicians within each age group using independent t-tests (Bonferroni's corrections for multiple comparisons were applied). Results showed that non-musicians performed on par with musicians until the 30 to < 40 year age group. In the 40 to <50 year age group, DDTs were significantly better in musicians than in non-musicians. The effect size (Cohen's d) was 1.764, denoting a large musicianship effect. Although musicians had better DDTs than non-musicians in the 50 to <60 age group, the difference did not reach statistical significance. The results of independent t-tests are given in Table 4.4.

Table 4.3

Summary of the results of pair-wise comparisons in Non-Musicians across different age groups on the duration discrimination test

Age in years	10 to <20	20 to <30	30 to <40	40 to <50
20 to <30	NS			
30 to <40	NS	NS		
40 to <50	NS	S	S	
50 to <60	NS	NS	NS	NS

Note. NS- Not Significant, S- Significant at 0.005 level (adjusted for Bonferroni's multiple comparisons)

Table 4.4

Results of Independent t-tests comparing Musicians and Non-Musicians within each age group on the duration discrimination test

Groups	Age Groups (in years)	t	df	Corrected p
Musicians and non-musicians	10 to <20	1.146	34	1.000
	20 to <30	0.308	40	1.000
	30 to <40	2.473	32	0.095
	40 to <50	4.831	28	0.005**
	50 to <60	2.525	37	0.080

Note. t-test statistic, df-degrees of freedom, p-significance level. Corrected p-value= (obtained p-value)*(number of pairwise comparisons made). If corrected p>1.000, the value is approximated to 1.000. **-sig. level at 0.01.

c. Gap Detection Test

Figure 4.3 shows the mean and one SD of Gap Detection Thresholds (GDTs) for both musician and non-musician groups across different ages. The Shapiro-Wilk test revealed a non-normal distribution in one out of the ten groups. The square root transformation resulted in a normal distribution of data across all age groups. The

results of Shapiro-Wilk's test of normality are given in Tables A9 to A13 of Appendix 2. All statistical analyses were conducted on transformed data; however, the original unit of measurement was used for graphical depiction.

Figure 4.3

Mean and one SD (error bars) of GDTs across different age groups in Musicians and Non-Musicians. Dots represent individual data points.

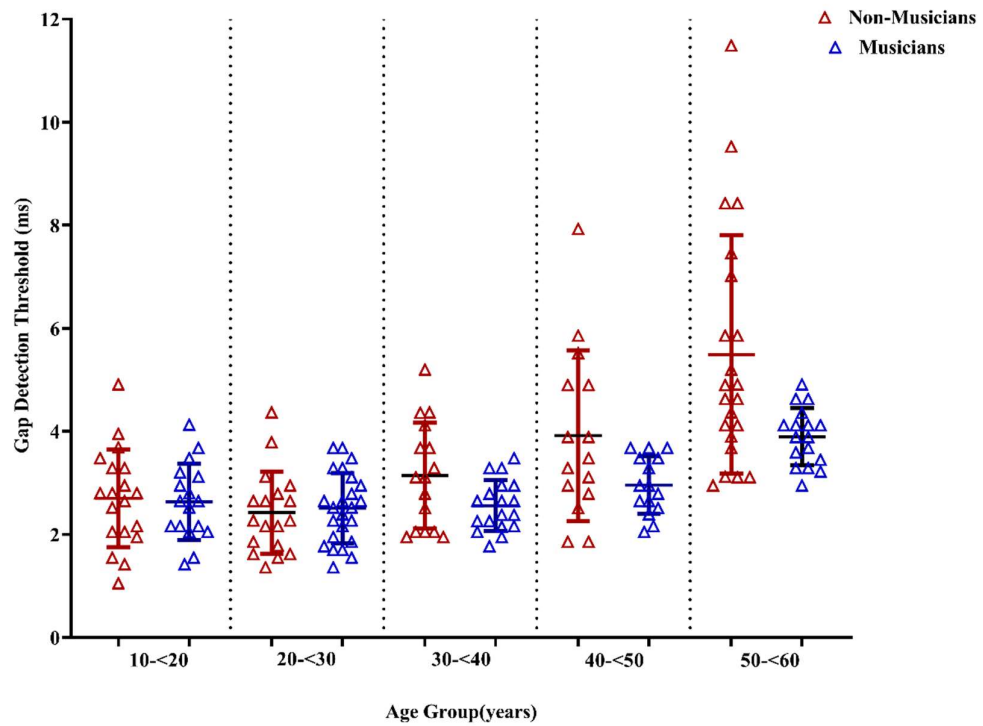


Figure 4.3 illustrates that the mean GDT in musicians was comparable to that of non-musicians, except in the 40 to <50 and 50 to <60-year age groups, where musicians exhibited better mean GDTs than non-musicians. Two-way ANOVA on GDTs demonstrated that there was a significant main effect of musicianship [$F(1,171)= 10.655$, $p=0.001$, $\eta^2p=0.059$], age [$F(4,171)= 25.819$, $p<0.001$, $\eta^2p=0.377$], and a significant interaction effect between age and musicianship

[$F(4,171)=2.653$, $p=0.035$, $\eta^2p=0.058$]. The interaction effect suggests that GDTs deteriorate with advancing age in both musicians and non-musicians, but at varying rates. With advancing age, the gap detection test performance deteriorated faster in non-musicians than in musicians.

One-way ANOVA was conducted separately for musicians and non-musicians to analyse the interaction effects. Results revealed a significant age effect in non-musicians [$F(4,85)=14.851$, $p<0.001$, $\eta^2p=0.411$], and in musicians [$F(4,86)=13.914$, $p<0.001$, $\eta^2p=0.393$]. The results of ANOVA demonstrated a large age effect (η^2p of 0.411 and 0.393) in non-musicians and musicians, respectively. Post-hoc analysis with Bonferroni's corrections indicated that GDTs deteriorated from 40 to <50 years in non-musicians. In musicians, significantly poorer performance on the gap detection test was observed only in those aged 50 to <60 years. The summary of the results of the pair-wise comparisons on GDT performance across age groups in non-musicians and musicians is given in Tables 4.5 and 4.6, respectively. Details of post-hoc test results with Bonferroni's correction applied to the p-value are given in Tables A16 and A17 of Appendix 2 for non-musicians and musicians, respectively.

Independent t-tests were performed to check the effect of musicianship in each age group. Independent t-test results with Bonferroni's corrections for multiple comparisons showed that non-musicians performed at the same level as musicians until 40 to <50 years. At 50 to <60 years of age, musicians performed better than non-musicians. The effect size (Cohen's d) was 0.906, demonstrating a large musicianship effect. The results of independent t-tests are given in Table 4.7.

Table 4.5

Summary of the results of pair-wise comparisons in Non-Musicians across different age groups on the gap detection test

Age in years	10 to <20	20 to <30	30 to <40	40 to <50
20 to <30	NS			
30 to <40	NS	NS		
40 to <50	NS	S	NS	
50 to <60	S	S	S	S

Note. NS- Not Significant, S- Significant at 0.005 level (adjusted for Bonferroni's multiple comparisons)

Table 4.6

Summary of the results of pair-wise comparisons in Musicians across different age groups on the gap detection test

Age in years	10 to <20	20 to <30	30 to <40	40 to <50
20 to <30	NS			
30 to <40	NS	NS		
40 to <50	NS	NS	NS	
50 to <60	S	S	S	S

Note. NS- Not Significant, S- Significant at 0.005 level (adjusted for Bonferroni's multiple comparisons)

Table 4.7

Results of Independent t-tests comparing Musicians and Non-Musicians within each age group on the gap detection test

Groups	Age Groups (in years)	t	df	Corrected p
Musicians and non-musicians	10 to <20	0.140	34	1.000
	20 to <30	0.444	40	1.000
	30 to <40	2.031	32	0.255
	40 to <50	2.017	28	0.265
	50 to <60	2.805	37	0.040*

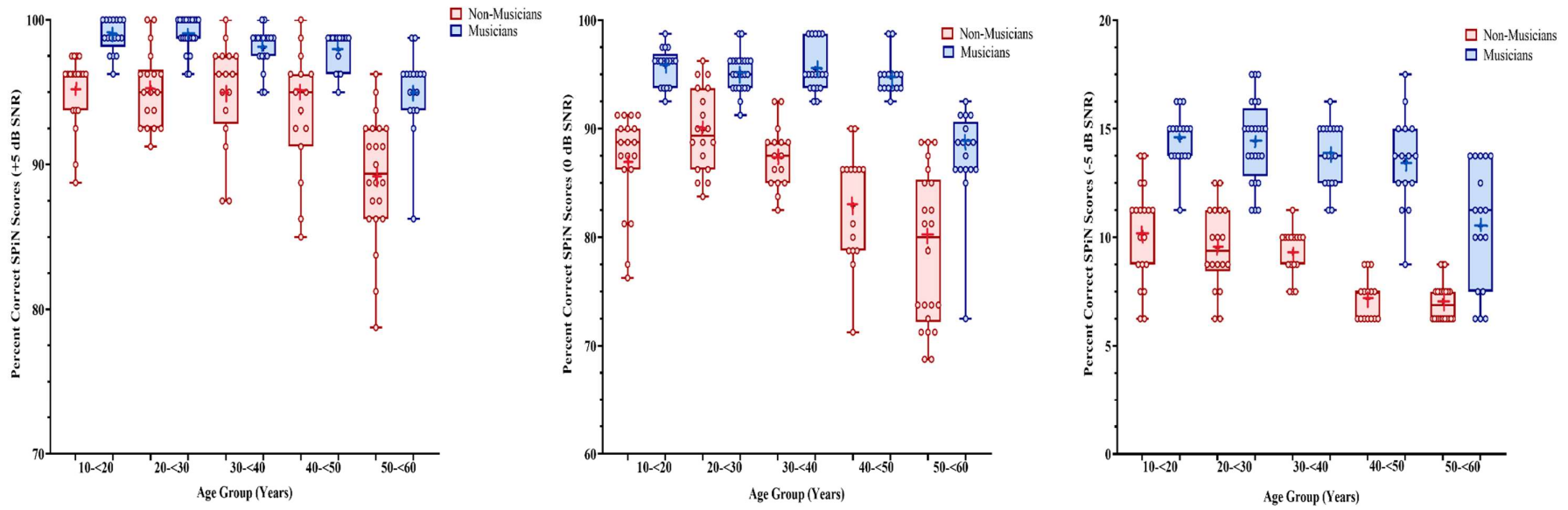
Note. t-test statistic, df-degrees of freedom, p-significance level. Corrected p-value= (obtained p-value)*(number of pairwise comparisons made). If corrected p>1.000, the value is approximated to 1.000. *-sig. level at 0.05.

Objective 2: SPiN

Figures 4.4 (a-c) show mean/median, interquartile range, and quartiles (Q1, Q2, and Q3) of percent correct SPiN scores at +5, 0, and -5 dB Signal to Noise Ratios (SNRs). The Shapiro-Wilk test revealed a normal distribution in 4 of 10 age groups ($p > 0.05$). Various transformations (e.g., square, square root, logarithmic, arcsine, or rationalized arcsine transformations) did not improve the normality of SPiN scores; hence, non-parametric analysis was carried out. The results of Shapiro-Wilk's test of normality are given in Tables A9 to A13 of Appendix 2.

Figures 4.4 (a, b, and c)

Panel showing the boxplots of percent correct SPiN scores at +5, 0, and -5 dB SNR across age groups in Musicians and Non-Musicians. Dots represent individual data points. The mean is denoted by the '+' sign. Boxplots represent the 25th (first quartile: Q1), 50th (second quartile: Q2), and 75th (third quartile: Q3) percentiles, and the whiskers represent 1.5 times the inter-quartile range (Difference between the third and first quartile: Q3-Q1)



From Figure 4.4, it can be inferred that the difference between mean percent correct SPiN scores in musicians and non-musicians was more pronounced at poorer SNRs, mainly in the middle and older age groups. Separate Kruskal-Wallis tests were performed (for musicians and non-musicians in each SNR) to assess the significance of differences in SPiN scores across different age groups. The results of the Kruskal-Wallis test for each SNR for musicians and non-musicians across age groups are given in Table 4.8.

Table 4.8

Results of the Kruskal-Wallis test at +5, 0, and -5 dB SNRs in musicians and non-musicians across age groups. Degrees of freedom (df)=4

	SNRs					
	+5 dB		0 dB		-5 dB	
	χ^2	p	χ^2	P	χ^2	p
Non-Musicians	28.014	<0.001	31.988	<0.001	39.492	<0.001
Musicians	36.114	<0.001	43.809	<0.001	25.715	<0.001

Note. χ^2 =chi-square test-statistic; p-significance level

The Kruskal-Wallis test indicated that SPiN scores significantly differed ($p<0.05$) across different age groups in both musicians and non-musicians at all three SNRs: +5, 0, and -5 dB. Further, Mann-Whitney U-tests with Bonferroni's corrections were performed to analyse the age differences in SPiN scores in detail. Results of the post-hoc analysis for three different SNRs in musicians and non-musicians are given in Table 4.9. As shown in Table 4.9, both non-musicians and musicians performed poorly in the 50 to <60 age group at +5 dB SNR. However, at 0 dB and -5 dB SNRs, SPiN abilities decreased in musicians at a later age (50 to <60 years) compared to non-musicians (40 to <50 years). The effect size (Cohen's r) ranged from 0.462 to 0, 859 indicating a moderate to large age effect. The summary

of the results of pair-wise comparisons across different age groups for musicians and non-musicians is presented in Tables 4.10, 4.11, and 4.12 for SNRs of +5, 0, and -5 dB, respectively.

Table 4.9

Results of the Mann-Whitney U-test on percent correct SPiN scores in Non-musicians and Musicians across age groups at +5, 0, and -5 dB SNRs

Age Group (years)	Non-Musicians (+5 dB SNR)		Musicians (+5 dB SNR)		Non-Musicians (0 dB SNR)		Musicians (0 dB SNR)		Non-Musicians (-5 dB SNR)		Musicians (-5 dB SNR)	
	Z	Corrected p	Z	Corrected p	Z	Corrected p	Z	Corrected p	Z	Corrected p	Z	Corrected p
1 & 2	0.499	1.000	0.255	1.000	1.467	1.000	1.391	1.000	0.975	1.000	0.232	1.000
1 & 3	0.221	1.000	1.830	0.670	0.451	1.000	0.757	0.670	1.522	1.000	1.488	0.670
1 & 4	1.138	1.000	2.177	0.300	2.558	0.110	1.786	0.740	3.678	<0.010**	1.698	0.900
1 & 5	4.462	<0.010**	4.455	<0.010**	3.701	<0.010**	5.011	<0.010**	4.230	<0.010**	4.302	<0.010**
2 & 3	0.314	1.000	2.224	0.440	1.860	0.630	0.026	0.440	0.391	1.000	1.045	1.000
2 & 4	0.822	1.000	2.574	0.100	3.319	<0.010**	1.091	0.500	3.461	<0.010**	1.294	0.090
2 & 5	4.324	<0.010**	4.847	<0.010**	4.419	<0.010**	5.365	<0.010**	4.021	<0.010**	4.086	<0.010**
3 & 4	0.976	1.000	0.262	1.000	2.278	0.230	0.838	1.000	3.968	0.230	0.483	1.000
3 & 5	3.725	<0.010**	3.703	<0.010**	3.598	<0.010**	5.061	<0.010**	4.552	<0.010**	3.555	<0.010**
4 & 5	2.813	0.050*	3.494	<0.010**	1.618	1.000	4.843	<0.010**	0.338	1.000	2.837	0.050*

Note. Age groups 1, 2, 3, 4, and 5 correspond to the age ranges of 10 to <20, 20 to <30, 30 to <40, 40 to <50, and 50 to <60 years, respectively. |Z|-test statistic, p-significance level, Corrected p-value= (obtained p-value) *(number of pairwise comparisons made). If corrected p>1.000, the value is approximated to 1.000.*-sig. level at 0.05; **- sig. level at 0.01.

Table 4.10

Summary of the results of pair-wise comparisons across different age groups in non-musicians and musicians on percent correct SPiN scores at +5 dB SNR.

Age in years	Non-Musicians				Musicians			
	10 to <20	20 to <30	30 to <40	40 to <50	10 to <20	20 to <30	30 to <40	40 to <50
20-<30	NS				NS			
30-<40	NS	NS			NS	NS		
40-<50	NS	NS	NS		NS	NS	NS	
50-<60	S	S	S	S	S	S	S	S

Note. NS- Not Significant, S- Significant at 0.005 level (adjusted for Bonferroni's multiple comparisons)

Table 4.11

Summary of the results of pair-wise comparisons across different age groups in non-musicians and musicians on percent correct SPiN scores at 0 dB SNR.

Age in years	Non-Musicians				Musicians			
	10 to <20	20 to <30	30 to <40	40 to <50	10 to <20	20 to <30	30 to <40	40 to <50
20-<30	NS				NS			
30-<40	NS	NS			NS	NS		
40-<50	NS	S	NS		NS	NS	NS	
50-<60	S	S	S	S	S	S	S	S

Note. NS- Not Significant, S- Significant at 0.005 level (adjusted for Bonferroni's multiple comparisons)

Table 4.12

Summary of the results of pair-wise comparisons across different age groups in non-musicians and musicians on percent correct SPiN scores at -5 dB SNR.

Age in years	Non-Musicians				Musicians			
	10 to <20	20 to <30	30 to <40	40 to <50	10 to <20	20 to <30	30 to <40	40 to <50
20-<30	NS				NS			
30-<40	NS	NS			NS	NS		
40-<50	S	S	NS		NS	NS	NS	
50-<60	S	S	S	NS	S	S	S	S

Note. NS- Not Significant, S- Significant at 0.005 level (adjusted for Bonferroni's multiple comparisons)

The SPiN abilities between musicians and non-musicians were compared in each age group and at each of the SNRs using the Mann-Whitney U test.

Bonferroni's corrections for multiple comparisons were applied. The results indicated that musicians performed better than non-musicians in all age groups ($p < 0.01$) at all three SNRs. The effect size (Cohen's r) ranged from 0.519 to 0.792, demonstrating a large musicianship effect at +5 dB SNR. At 0 dB SNR, the effect size ranged from 0.604 to 0.862, indicating a large musicianship effect. The effect size varied from 0.579 to 0.857, suggesting a large musicianship effect at -5 dB SNR as well. The results of the Mann-Whitney U tests are provided in Table 4.13.

Table 4.13

Results of Mann-Whitney U tests comparing Musicians and Non-Musicians within each age group on percent correct SPiN scores at +5, 0-, and -5-dB SNR

Age Groups	SPiN scores at +5 dB		SPiN scores at 0 dB		SPiN scores at- 5 dB	
	SNR		SNR		SNR	
	 Z 	Corrected p	 Z 	Corrected p	 Z 	Corrected p
10 to <20	4.756	<0.005**	5.158	<0.005**	4.770	<0.005**
20 to <30	4.224	<0.005**	4.220	<0.005**	5.148	<0.005**
30 to <40	3.031	0.020*	4.942	<0.005**	5.002	<0.005**
40 to <50	3.184	<0.005**	4.725	<0.005**	4.659	<0.005**
50 to <60	4.251	<0.005**	3.775	<0.005**	3.619	<0.005**

Note. |Z|-test statistic; p-significance level, Corrected p-value = (obtained p-value)*(number of pairwise comparisons made). *-sig. level at 0.05, **-sig. level at 0.01.

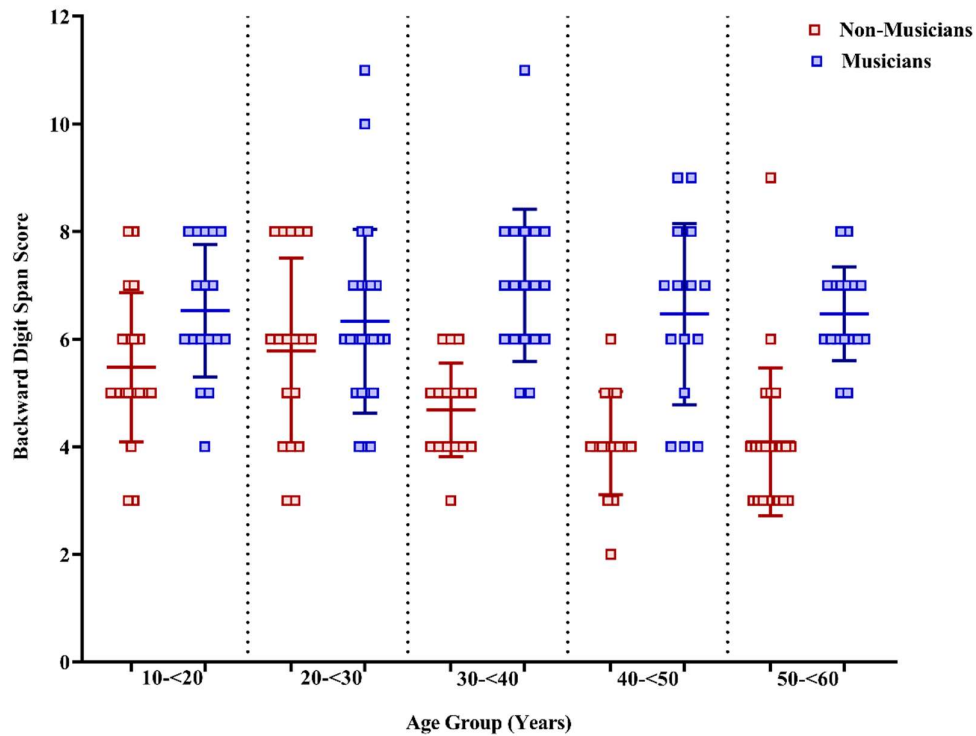
Objective 3: Working memory abilities

a. Backward Digit Span (BDS)

Figure 4.5 shows the Mean and one SD of BDS scores for musicians and non-musicians across different age groups. The Shapiro-Wilk test revealed a non-normal distribution for some age groups. The results of Shapiro-Wilk's test of normality are given in Tables A9 to A13 of Appendix 2. The square root transformation yielded a normal distribution for nine age groups (out of 10). Therefore, all statistical analyses were performed on the transformed scores; however, the actual values were used in the diagrammatic representations.

Figure 4.5

Mean and one SD (error bars) for BDS scores across different age groups in Musicians and Non-Musicians. Dots represent individual data points



A two-way ANOVA was carried out on BDS scores with musicianship and age groups as the between-subject factors. The results revealed the main effect of musicianship [$F(1,171)= 75.685$, $p<0.001$, $\eta^2p=0.307$], age [$F(4,171)= 3.243$, $p=0.014$, $\eta^2p=0.071$], and a significant interaction effect of musicianship and age [$F(4,171)= 4.157$, $p=0.003$, $\eta^2p=0.089$]. The interaction effect indicates that aging affected BDS scores differentially in musicians and non-musicians. From Figure 4.5, it can be seen that the BDS scores deteriorated at an earlier age in non-musicians compared to musicians. A one-way ANOVA was carried out separately in musicians and non-musicians to further understand the interaction effects. Results showed a significant main effect of age on BDS scores in non-musicians [$F(4,85)= 6.462$, $p<0.001$, $\eta^2p=0.233$]. However, musicians did not show any age

effect, indicating similar performances across all age groups. The effect size (η^2p) was 0.233, signifying a large age effect in non-musicians. Post-hoc analysis with Bonferroni's corrections was carried out. The BDS scores deteriorated significantly from 40 to <50 years onwards in non-musicians. The summary of the results of pair-wise comparisons for non-musicians on BDS scores is shown in Table 4.14. Details of post-hoc test results with Bonferroni's corrections applied to the p-value are given in Table A18 of Appendix 2.

Independent t-tests with Bonferroni's corrections were run to check the effect of musicianship in each age group. Results revealed that non-musicians performed at par with musicians till 20 to <30 years. Musicians performed better than non-musicians from 30 to <40 years of age onwards. The effect size (Cohen's d) spanned from 1.746 to 2.102, suggesting a large musicianship effect. The results of the independent t-tests are given in Table 4.15.

Table 4.14

Summary of the results of pair-wise comparisons in Non-Musicians across different age groups on BDS scores

Age in years	10 to <20	20 to <30	30 to <40	40 to <50
20 to <30	NS			
30 to <40	NS	NS		
40 to <50	S	S	NS	
50 to <60	S	S	NS	NS

Note. NS- Not Significant, S- Significant at 0.005 level (adjusted for Bonferroni's multiple comparisons)

Table 4.15

Results of Independent t-tests comparing Musicians and Non-Musicians within each age group on BDS scores

Groups	Age Groups (in years)	t	df	Corrected p
Musicians and non- musicians	10 to <20	2.406	34	0.110
	20 to <30	1.105	40	1.000
	30 to <40	5.919	32	<0.005**
	40 to <50	4.781	28	<0.005**
	50 to <60	6.511	37	<0.005**

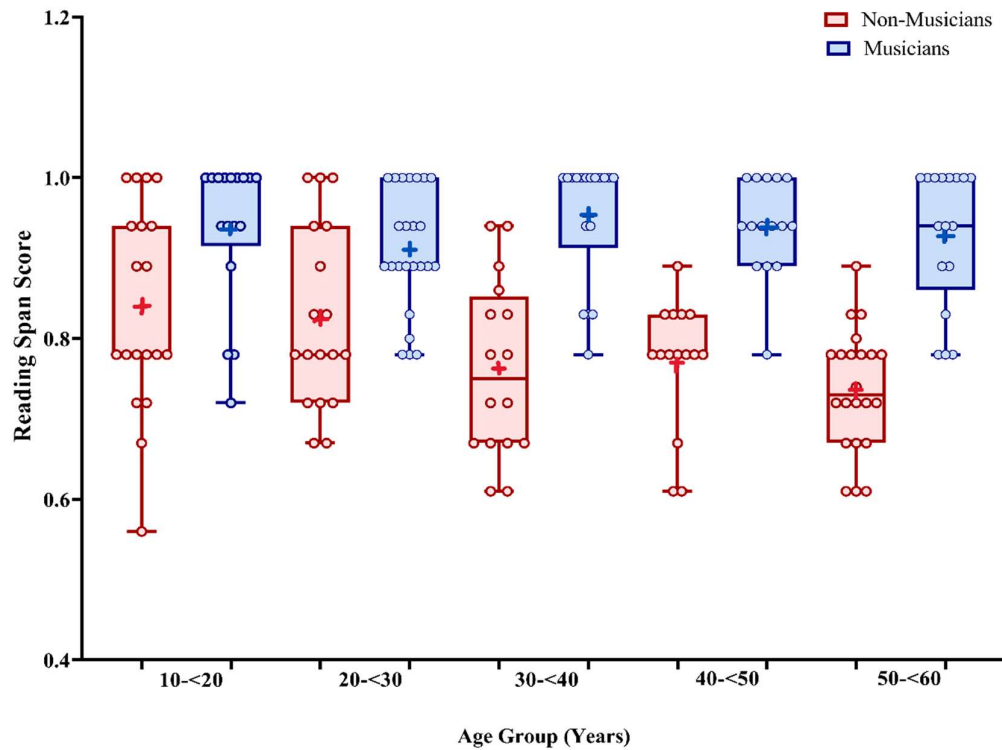
Note. t-test statistic, df-degrees of freedom, p-significance level, Corrected p-value = (obtained p-value)*(number of pairwise comparisons made). If corrected $p > 1.000$, the value is approximated to 1.000. **-sig. level at 0.01.

b. Reading Span (RS)

Figure 4.6 shows the Mean/median, inter-quartile range, and quartiles (Q1, Q2, and Q3) of RS scores across different age groups in musicians and non-musicians. The Shapiro-Wilk test revealed normal distribution in 4 of the 10 age groups ($p > 0.05$). The results of Shapiro-Wilk's test of normality are given in Tables A9 to A13 of Appendix 2. Different transformations (square, square root, logarithmic, arcsine, etc) did not improve the normality of the distributions across different age groups; hence, non-parametric analysis was done.

Figure 4.6

Boxplot of RS scores across age groups in Musicians and Non-Musicians. Dots represent individual data points. The mean is shown as the '+' sign. Boxplots represent the 25th, 50th, and 75th percentiles, and the whiskers represent 1.5 times the interquartile range.



From Figure 4.6, it is evident that musicians show a consistent mean RS score across age groups; however, non-musicians show a slight deterioration in the older age group. To assess the age effects separately in musicians and non-musicians, the Kruskal-Wallis test was administered. There was a significant difference in reading span scores across the age groups in non-musicians, $\chi^2(4) = 10.087$, $p = 0.039$. However, musicians did not exhibit significant differences across age groups. Post-hoc analysis using the Mann-Whitney U-test (with Bonferroni's corrections) in non-musicians indicated that differences in the reading span scores between younger and older age groups did not reach statistical significance.

To check the effect of musicianship in each age group, Mann-Whitney U tests (and Bonferroni's corrections for multiple comparisons) were administered. The results revealed that non-musicians performed at the same level as musicians in the younger age group. From 20 to <30 years of age, musicians performed better than non-musicians. The effect size (Cohen's r) extended from 0.394 to 0.790, indicating a medium to large musicianship effect. The results of the Mann-Whitney U-tests are given in Table 4.16.

Table 4.16

Results of Mann-Whitney U-tests comparing Musicians and Non-Musicians within each age group on RS scores

Groups	Age Groups (in years)	Z	Corrected 'p'
Musicians and non-musicians	10 to <20	2.410	0.080
	20 to <30	2.559	0.050*
	30 to <40	4.250	<0.005**
	40 to <50	4.329	<0.005**
	50 to <60	4.675	<0.005**

Note. |Z|-test statistic, p-significance level. Corrected p-value= (obtained p-value) *(number of pairwise comparisons). If corrected $p > 1.000$, the value is approximated to 1.000. *-sig. level at 0.05, **- sig. level at 0.01.

In the current study, dependent variables, namely PDT, DDT, GDT, and BDS, followed a normal distribution after a square root transformation. The mean and one SD values of the transformed PDT, DDT, GDT, and BDS measures are given in Tables A19, A20, A21, and A22, respectively, given in Appendix 2.

Objective 4: The relationship among age, psychoacoustic abilities, speech perception in noise, and working memory abilities in both musician and non-musician groups.

To examine the relationship between age, psychoacoustic abilities, SPiN, and working memory abilities in musician and non-musician groups, Principal Component Analysis (PCA) was conducted (Jolliffe, 1973; King & Jackson, 1999). Previous studies have employed similar approaches to investigate the relationships among variables in their respective studies (Carcagno & Plack, 2022; Dejonckere & Lebacqz, 1996; Hu, 1999; Zhang & Castelló, 2017). Since nearly half of the selected measures violated the assumption of normality, a non-parametric PCA was performed separately for the musician and non-musician groups. The program was written in the syntax editor of the Statistical Package for Social Sciences software (version 26) using Spearman's correlation. Varimax rotation was used. The variables included in the PCA were age, PDT, DDT, GDT, BDS scores, RS scores, and percent correct SPiN scores at +5, 0, and -5 dB SNRs separately for both musicians and non-musicians. Kaiser-Meyer-Olkin (KMO) test and Bartlett's test of sphericity were administered to assess whether the data were appropriate for PCA.

The KMO test assesses sampling adequacy for each variable in the model and for all variables considered for PCA. A sampling adequacy measure greater than 0.6 (Kaiser, 1974) is required to administer the PCA on a dataset. In the current study, the KMO values obtained for non-musicians and musicians were 0.746 and 0.681, respectively, indicating that the dataset was suitable for conducting a PCA. The Bartlett's Test of Sphericity is used to determine whether the correlation matrix of the chosen variables significantly differs from an identity

matrix. An identity matrix has 1s along its diagonal and 0s in all off-diagonal positions. If the chi-squared test is significant ($p < 0.05$), it means that the dataset variables are correlated and suitable for PCA. Bartlett's test of sphericity on the data set revealed that the variables were sufficiently correlated ($p < 0.001$); hence, the data were suitable for conducting a PCA (Bartlett, 1954).

Factor loadings are coefficients that represent the extent to which each original variable contributes to a principal component. The loadings indicate which variables play the most important role in explaining the variance accounted for by the principal components. Loadings close to 1 or -1 indicate that the factor has a strong influence on the variable (Webster, n.d.). They are obtained from the eigenvectors of the data's covariance or correlation matrix.

The non-parametric PCA revealed that, among non-musicians, the extracted components explained a total variance of 50.81%. A scree plot is a simple graphical tool used in PCA to help decide how many components or factors to keep. Examination of the scree plot denoted an inflection point after the second component, suggesting that preserving two components (with eigenvalues greater than 1) can adequately capture the underlying structure of the data. Out of the two components, two out of three psychoacoustic measures and age were strongly loaded on component 2. SPiN, working memory, and DDT were strongly loaded on component 1. Thus, SPiN (percent correct SPiN scores at +5 and 0 dB SNR) and working memory measures were strongly correlated, whereas psychoacoustic measures (PDT and GDT) were correlated with age and SPiN scores at -5 dB SNR in non-musicians. Table 4.17 shows the results of PCA in non-musicians. Table 4.18 provides information on the components, the variables with factor loadings, and the percentage of variance accounted for by each component.

Table 4.17

Loadings of principal components identified by PCA on psychoacoustic, SPiN, and working memory measures in non-musicians

Sl. No.	Variables	Component	
		1	2
1.	% Correct SPiN at 0 dB SNR	0.827	
2.	% Correct SPiN at +5 dB SNR	0.716	
3.	RS	0.566	
4.	BDS	0.435	
5.	DDT	-0.396	
6	PDT		0.841
7.	Age		0.701
8.	GDT		0.615
9.	% Correct SPiN -5 dB SNR		-0.523

Table 4.18

PCA results indicating the two components, the corresponding factor loadings, and the percentage of variance for each component in non-musicians

Components	Factor Loadings	Percentage of Variance
Component 1	Percent correct SPiN scores at 0 and +5 dB SNRs, RS, BDS scores, and DDT	27.92
Component 2	PDT, GDT, age, and percent correct SPiN scores at -5 dB SNR	22.88

In musicians, a total variance of 64.63 % was accounted for by the extracted components. Examination of the scree plot revealed an inflection point after the third component, suggesting that retaining three components can adequately capture the underlying structure of the data. Among psychoacoustic measures, PDT was strongly loaded onto component 2, along with the working memory measures, indicating a correlation between the two. DDT was the only variable loaded onto component 3, and GDT was loaded onto component 1, with SPiN scores and age showing a strong correlation between these variables. Thus, SPiN measures were strongly loaded on component 1, while working memory measures were loaded on component 2, whereas the psychoacoustic measures were loaded on all three components. In contrast to the non-musicians, musicians showed no correlation between SPiN and working memory measures. Table 4.19 presents the results of the PCA analysis for musicians. Table 4.20 presents details on the components, the variables with high factor loadings, and the percentage of variance explained by each component.

Table 4.19

Loadings of principal components identified by PCA on psychoacoustic, SPiN, and working memory measures in musicians

Sl. No.	Variables	Component		
		1	2	3
1	% Correct SPiN at 0 dB SNR	0.865		
2	Age	-0.847		
3	% Correct SPiN at +5 dB SNR	0.805		
4	GDT	-0.743		
5	% Correct SPiN at -5 dB SNR	0.672		
6	BDS		0.755	
7	PDT		-0.670	
8	RS		0.693	
9	DDT			0.975

Table 4.20

PCA results indicating the three components, the corresponding factor loadings, and the percentage of variance for each component in musicians

Components	Factor Loadings	Percentage of Variance
Component 1	Age, percent correct SPiN scores at 0, +5 dB and -5 dB SNR and GDT	35.08
Component 2	BDS, RS, and PDT	17.63
Component 3	DDT	11.91

Test-Retest Reliability

Out of a total sample size of 181 subjects (N=181), 20 (10 musicians and 10 non-musicians, i.e., two musicians and two non-musicians in each of five age groups) were randomly chosen to assess the test-retest reliability after three months of initial testing. The psychoacoustic, SPiN, and working memory measures were re-evaluated, and the results of the initial and subsequent testing were correlated to determine the reliability of test results. The Intraclass Correlation Coefficient (ICC) measure was used to determine the test-retest reliability of study results. The ICC coefficient is classified as ‘r’ <0.5= poor reliability, ‘r’ = 0.5 to 0.75= moderate reliability, ‘r’ = 0.75 to 0.9 =good reliability, and ‘r’> 0.9 = excellent reliability (Koo & Li, 2016). The ICC was run using a two-way mixed effects model and an absolute agreement measure. The ICC coefficients of psychoacoustic measures PDT, DDT, and GDT are given in Table 4.21. The results indicate a moderate to excellent reliability on psychoacoustic measures.

Table 4.21

Results of ICC test showing ICC coefficient, significance level (p), and degree of reliability on PDT, DDT, and GDT.

Measures	ICC Coefficient	p-value	Reliability
PDT	0.924	<0.001	Excellent
DDT	0.624	0.007	Moderate
GDT	0.879	<0.001	Good

The ICC coefficients of percent correct SPiN scores at +5, 0, and -5 dB SNR are given in Table 4.22. The results indicate a moderate to good reliability on SPiN measures.

Table 4.22

Results of ICC test showing ICC coefficient, significance level ('p'), and degree of reliability on percent correct SPiN scores

Measures of % Correct SPiN	ICC Coefficient	p-value	Reliability
+5 dB SNR	0.689	<0.001	Moderate
0 dB SNR	0.894	0.007	Good
-5 dB SNR	0.884	<0.001	Good

The ICC coefficients of working memory measures, namely the BDS and RS scores, are given in Table 4.23. The results indicate a moderate to good reliability on working memory measures.

Table 4.23

Results of ICC test showing ICC coefficient, significance level ('p'), and degree of reliability on BDS and RS scores

Measures	ICC Coefficient	p-value	Reliability
BDS	0.835	<0.001	Good
RS	0.651	0.007	Moderate

CHAPTER 5

DISCUSSION

The current study aimed to assess the age effects on psychoacoustic abilities, speech perception in noise (SPiN), and working memory abilities in musicians and non-musicians across a range of age groups (10 to <20, 20 to <30, 30 to <40, 40 to <50, and 50 to <60 years). Within each age group, the study also compared the performances of musicians and non-musicians on psychoacoustic, SPiN, and working memory abilities. In addition, the study aimed to determine the association between age, psychoacoustic, SPiN, and working memory abilities in musicians and non-musicians.

A total of 181 participants (91 musicians, 90 non-musicians) were included. Musicians had a minimum of five years (in the 10 to < 20 year age group) and ten years (in the other age groups) of training in Carnatic classical music. Both groups had normal otological, audiological, and cognitive status. Musicians scored significantly higher on Mini Profile of Music Perception Skills and Edinburgh Lifetime Musical Experience Questionnaire ($p < 0.05$), reflecting the positive impact of music training, as other measures were matched between groups. The World Health Organization Quality of Life Brief mean scores and the one-minute noise questionnaire showed no group differences.

Objective 1: Psychoacoustic abilities

Participants' psychoacoustic abilities were assessed using Pitch Discrimination Threshold (PDT), Duration Discrimination Threshold (DDT), and Gap Detection Threshold (GDT). A two-way analysis of variance was used to examine the effects of age and musicianship. Results showed significant effects of

musicianship and its interaction with age for all measures. Non-musicians exhibited declines in PDT and GDT beginning at 40 to <50 years, and at 40 to <50 years for DDT, while musicians did not show a similar drop in performances for PDT and DDT. Declines in GDT for musicians appeared a decade later at 50 to <60 years, indicating a delayed age-related decline compared to non-musicians. Overall, musicians consistently outperformed non-musicians in middle and older age groups, reflecting the preservation of auditory discrimination and temporal processing abilities through musical training.

Aging leads to a decline in individuals' perceptual abilities. Age-related declines in pitch discrimination were first noted by Konig (1957) and later confirmed by other studies (Clinard et al., 2010; Fitzgibbons & Gordon-Salant, 2001; He et al., 1998; Jain & Kumar, 2016; Pichora-Fuller & Singh, 2006; Parbery-Clark et al., 2012). Similar reductions are observed in duration discrimination (Pichora-Fuller et al., 1995; Schneider et al., 2002; Strouse et al., 1998; Tremblay et al., 2003) and temporal resolution tasks such as gap detection and temporal ordering (Fitzgibbons & Gordon-Salant, 1994, 1995, 1996, 2009; Humes & Dubno, 2009; Phillips et al., 1994; Pichora-Fuller et al., 2006; Schneider & Hamstra, 1999), independent of hearing loss (Fitzgibbons & Gordon-Salant, 1994; Lister et al., 2000, 2002). An earlier study found that temporal processing abilities, such as gap detection and duration discrimination, generally start to decline around the fourth decade of life (Kumar & Sangamanatha, 2011) and continues with age (Braga et al., 2015; Grose & Mamo, 2010; Lunardelo et al., 2024; Mussoi & Brown, 2019; Snell, 1997).

In the present study, non-musicians showed a significant decline in DDT in the 40 to <50 year age group, but not in the 50 to <60 year age group, indicating

mild deterioration without significant group differences compared to younger age groups. However, no significant difference was observed between the 40–<50 and 50–<60 age groups, indicating comparable performances that did not reach statistical significance. Consistent with Nisha et al. (2022), non-musicians exhibited age-related declines in binaural temporal processing, whereas musicians showed delayed or absent age effects, suggesting that musical training may mitigate or postpone temporal processing deficits.

Age-related auditory decline results from changes in the peripheral, neural, and central auditory systems. Peripheral factors, namely outer hair cell loss, basilar membrane stiffening, and spiral ganglion neuron damage, reduce pitch and temporal processing (Makary et al., 2011; Ruggero & Temchin, 2005; Schuknecht & Gacek, 1993), poorer frequency selectivity, and reduced neural synchrony (Clinard et al., 2010; Frisina & Walton, 2006). Central changes, including reduced synchrony, weaker inhibition, and impaired frequency coding, further affect temporal processing and brainstem responses (Anderson, 1973; Burkard & Sims, 2002; Caspary et al., 2008). Cognitive aging, characterized by reduced prefrontal function and compromised myelin integrity, affects working memory, attention, and timing (Alain et al., 2001; Peters, 2002). Aging reduces gamma-aminobutyric acid levels, disrupting the balance of excitatory and inhibitory inputs and impairing temporal processing and speech-in-noise perception (Mills, 2021). Additionally, decreased gamma-aminobutyric acid levels delay fine temporal processing (Bertoli et al., 2002; Caspary et al., 2008), and delayed auditory nerve recovery reduces sensitivity to rapid changes, affecting gap detection (Alain et al., 2004; Schneider & Hamstra, 1999).

Musicians exhibit superior temporal and pitch processing abilities compared to non-musicians. Studies have consistently shown enhanced duration discrimination (Banai et al., 2012; Grassi et al., 2017; Guclu et al., 2011; Kumar et al., 2016; Sangamanatha et al., 2012) and improved temporal resolution in gap detection tasks (Ding et al., 2022; Donai & Jennings, 2016; Elangovan et al., 2016; Jain et al., 2014; Kumar et al., 2016; Mishra et al., 2014; Pirouzmand et al., 2021; Psarris et al., 2024; Rammsayer & Altenmüller, 2006; Sangamanatha et al., 2012; Weaver et al., 2020). Superior pitch perception in musicians is associated with structural and functional adaptations in right-hemisphere regions, including the superior temporal gyrus, Heschl's gyrus, insula, and inferior frontal gyrus (Besson et al., 2007; Hyde et al., 2008; Zatorre et al., 2002), facilitating pitch tracking and tonal memory (Jiang et al., 2023; Tseng et al., 2019). Additionally, subcortical regions such as the inferior colliculus show enhanced activation and neural synchrony (Musacchia et al., 2007; Parbery-Clark et al., 2009b; Wong & Perrachione, 2007).

Morphometric and neuroimaging studies indicate that musicians exhibit greater gray matter in auditory, motor, and cognitive regions such as Heschl's gyrus, premotor cortex, and corpus callosum (Gaser & Schlaug, 2003; Keenan et al., 2001; Schlaug, 2001), along with stronger activation in auditory, motor, visual, and emotion-related areas including the hippocampus and amygdala (Gaab & Schlaug, 2003; Levitin & Tirovolas, 2009; Zatorre et al., 2007). Meta-analyses further confirm increased gray and white matter volumes and enhanced neural activation resulting from both long- and short-term training (Criscuolo et al., 2022), reflecting precise neural timing, stronger phase-locking, and heightened plasticity (Strait & Kraus, 2014; Zendel & Alain, 2012). These findings collectively support

the results of the present study, emphasizing the positive influence of musical training on auditory perception.

Age-related auditory declines are more pronounced in non-musicians, whereas lifelong musical training enhances cognitive reserve, facilitating perceptual, attentional, and cognitive flexibility in aging (Zendel & Alain, 2012). Music practice promotes neural efficiency and compensatory activity, reflecting auditory plasticity (Grassi et al., 2017; Nisha et al., 2022). Regular exposure to complex acoustic patterns improves sensitivity to pitch and duration changes, strengthening psychoacoustic and speech perception abilities (Chasin, 2003; Glasberg & Moore, 1989). Long-term training further induces structural and functional changes that enhance auditory discrimination and temporal resolution in older adults (Besson et al., 2011).

These protective effects of music training may emerge as early as the third or fourth decade of life, coinciding with age-linked perceptual declines in non-musicians. The current study supports these findings, highlighting the role of musical training in delaying age-related auditory decline. The objective of the study was to investigate the influence of music training on age-related changes in perceptual abilities by comparing musicians and non-musicians across an age continuum. The present study's findings affirm the hypothesis that musical training mitigates age-associated perceptual decline.

Based on these results, the null hypothesis "There is no significant difference in psychoacoustic abilities across different age groups (10 to <20, 20 to <30, 30 to <40, 40 to <50, and 50 to <60 years) between and within musicians and non-

musicians on: a. Pitch Discrimination Test b. Duration Discrimination test, and c. The Gap Detection test” was rejected.

Objective 2: SPiN

Participants’ SPiN abilities were evaluated, and percentage-correct scores were analysed using the Kruskal–Wallis test, followed by Mann–Whitney U tests with Bonferroni’s corrections. Significant age effects were observed across all three signal-to-noise ratio (SNR) conditions in both groups. In non-musicians, SPiN performance began to decline from 40 to <50 years, whereas in musicians, this decline appeared later, at 50 to <60 years, particularly at 0 and -5 dB SNRs. Across all age groups and SNRs, musicians consistently outperformed non-musicians ($p < 0.05$).

Older adults generally require higher SNRs than younger adults to achieve comparable speech-in-noise performance (Buss et al., 2019; Desjardins & Doherty, 2013; Helfer & Freyman, 2014; Taitelbaum-Swead & Fostick, 2016). This is because the background noise impairs their working memory and speech recall abilities (Heinrich et al., 2008; Pichora-Fuller & Souza, 2003). Older adults are particularly vulnerable in speech-in-speech conditions due to declines in central auditory processing, including reduced temporal resolution, slower processing, and poorer consonant recognition, which are linked to both cognitive and perceptual aging (Frisina & Frisina, 1997; Füllgrabe et al., 2015). Age effects are most pronounced with speech maskers that involve both energetic and informational masking, particularly with 2- to 3-talker babble (Freyman et al., 2004; Rosen et al., 2013).

Aging causes microstructural damage in the middle longitudinal fasciculus, which is crucial for vocabulary, sequencing, and complex processing, thereby affecting auditory processing (Tremblay et al., 2019; Wong et al., 2009). SPiN difficulties in older adults are associated with cortical thinning in auditory and speech-related areas (superior temporal cortex, ventral premotor cortex, inferior frontal gyrus) and executive regions (dorsal anterior insula, anterior cingulate, medial frontal cortex) (Bilodeau-Mercure et al., 2015; Harris et al., 2009; Tremblay et al., 2021). Grey matter loss in auditory regions further impairs speech understanding, increasing reliance on working memory and attention (Minkova et al., 2017).

Physiological aging leads to reduced neural synchrony, impaired temporal coding, delayed adaptation, and weaker inhibition from gamma-aminobutyric acid (Goossens et al., 2016; Grassi et al., 2017), resulting in central auditory processing deficits, such as poorer temporal resolution and slower responses (Frisina & Frisina, 1997). Cognitive abilities and temporal fine structure sensitivity are the best predictors of SPiN performance, even in individuals with normal hearing (Füllgrabe et al., 2015). Thus, older adults' reduced ability to suppress irrelevant sounds, slower processing, and memory decline contribute further to SPiN challenges (Fitzgibbons & Gordon-Salant, 2010; Tun et al., 2002). In contrast, better working memory and temporal resolution are known to enhance SPiN performance (Parbery-Clark et al., 2011).

Musical training leads to structural brain changes that promote neuroplasticity, resulting in a larger corpus callosum, increased grey matter in auditory, motor, and visuospatial regions, and stronger brain connectivity (Gaser & Schlaug, 2003; Groussard et al., 2014; Luo et al., 2012). Young musicians show

stronger and earlier speech-evoked auditory brainstem responses in noise, indicating enhanced SPiN processing and subcortical–cortical plasticity (Parbery-Clark et al., 2009a). Grey matter increases are most pronounced in highly skilled musicians (Gaser & Schlaug, 2003). Although aging typically reduces temporal resolution and affects rapid speech perception (Humes et al., 2013), such effects appear later in musicians, likely due to long-term training–induced brain adaptations.

The expanded OPERA hypothesis (Patel, 2014) proposes that musical training enhances speech processing by engaging overlapping auditory and cognitive networks, promoting neural plasticity. It highlights five factors — Overlap, Precision, Emotion, Repetition, and Attention — through which music strengthens shared neural circuits. Consequently, sustained training improves speech processing, as reflected in the current findings. Meta-analytic evidence shows that musicians outperform non-musicians on SPiN tasks, particularly at low SNRs (<0 dB) (Maillard et al., 2023), supported by stronger subcortical speech encoding (Parbery-Clark et al., 2009a; Zendel & Alain, 2012). Interestingly, some studies report no clear benefit (Boebinger et al., 2015; Madsen et al., 2017), which may be attributed to methodological or sample/ participant differences.

Some studies suggest that non-verbal intelligence quotient may influence SPiN performance (Boebinger et al., 2015; Fuller et al., 2014), while others attribute musicians’ advantage to superior processing of acoustic cues (Fuller et al., 2014), reflecting the equivocal contributions of the working memory and temporal resolution abilities on SPiN performances. Musicians show enhanced SPiN through better pitch tracking, syllable and prosody discrimination, and stronger working memory (Maillard et al., 2023; Strait et al., 2014; Zuk et al., 2013). Music training

is known to promote top-down auditory learning and brain plasticity (Hennessy et al., 2022; Patel, 2011), though innate perceptual abilities may also contribute. Even amateur singing can reduce age-related SPiN decline (Tremblay et al., 2021). Hennessy et al. (2022) reported a moderate musician advantage ($g = 0.58$), independent of intelligence quotient and age. Consistent with prior findings (Maillard et al., 2023; Strait et al., 2014; Zendel & Alain, 2012), the current study also demonstrates an age-independent SPiN benefit in musicians, characterized by delayed decline and the strongest advantage at lower SNRs, suggesting that music training supports auditory resilience and promotes healthy aging.

Based on these outcomes, the null hypothesis “There is no significant difference between speech perception in noise scores across different age groups (10 to <20, 20 to <30, 30 to <40, 40 to <50 and 50 to <60 years) between and within musicians and non-musicians at three different SNRs a. -5dB, b. 0dB and c.+5dB” was rejected.

Objective 3: Working memory abilities

The results of the current study indicated that musicians showed a definite advantage compared to non-musicians on working memory tasks in the middle to older age groups. From 30 to <40 years onwards, musicians outperformed non-musicians on the Backward Digit Span (BDS) test, and from 20 to <30 years onwards, musicians outperformed non-musicians on the Reading Span (RS) test. Non-musicians exhibited an age-related decline in performance on the BDS test beginning from 40 to <50 years, whereas their RS test performance remained unaffected with aging. However, musicians did not show age effects in either of the tests.

The BDS task measures complex verbal working memory by testing one's ability to hold and manipulate verbal information (Owen et al., 2005). Earlier studies found little difference between musicians and non-musicians on this task due to its difficulty. While musically trained children performed better on simpler tasks, such as forward digit span, no advantage was observed on BDS (Hansen et al., 2013; Lee et al., 2007). In contrast, the current study showed an early onset of aging in non-musicians and a significant musicianship advantage on BDS. The RS task, another key working memory test, assesses the simultaneous storage and processing of information (Daneman & Carpenter, 1980) and is linked to reading and academic performance (Alloway et al., 2004). The current study revealed a musicianship advantage in the young, middle, and older age groups on the RS test; however, the age effects occurred similarly in both musicians and non-musicians.

Aging is associated with reduced white matter (Bucur et al., 2008), brain atrophy (Resnick et al., 2003), and microstructural decline (Morrison & Hof, 1997). Tasks requiring information manipulation are more affected than simple maintenance due to neuronal loss in the parietal and dorsolateral prefrontal cortices (Kawagoe et al., 2015; Rizio & Diaz, 2016; Thurm et al., 2018). Older adults exhibit reduced sensory and attentional activity (Ding et al., 2025) and a greater reliance on frontal regions, which may reflect compensation or reduced specialization (Goh & Park, 2009; Goh, 2011; Park et al., 2004). Declines in executive and hippocampal functions further impair working memory (Buckner, 2004). The working memory decreases with age due to reduced processing capacity and slower processing speed (Andiel & Liu, 1995; Borella et al., 2010, 2014; Brum et al., 2020; Gerhardsson et al., 2019; Hara & Naveh-Benjamin, 2015; López-Higes et al., 2018).

Conversely, musicians exhibit distinct neuroanatomical advantages, including a well-developed auditory cortex (Helmbold et al., 2005), a larger planum temporale, increased left-hemisphere activation (Schlaug et al., 1995), and greater grey matter volume (Münste et al., 2002), which support enhanced working memory. They demonstrate more efficient auditory processing (Tervaniemi et al., 2005), superior audiovisual integration (Talamini et al., 2016), and effective memory strategies, such as chunking (Talamini et al., 2017). Music training benefits both auditory and general cognitive functions (Román-Caballero et al., 2018). Lifelong musicians exhibit slower cognitive decline, reduced risk of dementia (Verghese et al., 2003), increased grey matter in perceptual and motor areas (Gaser & Schlaug, 2003), and stronger white matter connectivity (Bengtsson et al., 2005).

Musicians typically show superior auditory working memory, verbal memory (Chan et al., 1998; Forgeard et al., 2008; Talamini et al., 2016), auditory attention (Strait et al., 2010), and processing speed (Parbery-Clark et al., 2011), often performing better on verbal tasks and intelligence quotient measures (Glenn Schellenberg, 2011). These advantages may stem from training or innate abilities (Swaminathan et al., 2017), as some studies report no clear working memory benefits (Helmbold et al., 2005; Smayda et al., 2015). Another study revealed that lifelong training does not always ensure superior working memory (Hanna-Pladdy & MacKay, 2011). These differences could be due to procedural and participant differences, as well as the type and duration of musical training provided.

Musical training likely enhances memory through improved perception (Jakobson et al., 2003) and effective encoding strategies, such as rehearsal and semantic organization (Franklin et al., 2008; Jakobson et al., 2008). Musicians

outperform non-musicians on working memory and long-term memory tasks, possibly due to the use of subvocal rehearsal (Franklin et al., 2008; Hansen et al., 2013). Meta-analytic evidence has shown moderate benefits in verbal working memory for musicians (Talamini et al., 2017), which is attributed to enhanced auditory encoding (Rammsayer & Altenmüller, 2006; Talamini et al., 2016). This advantage is most evident for verbal material, supporting the stimulus modality hypothesis, and may underlie better phonological awareness and reading skills (Anvari et al., 2002).

Thus, in light of observed working memory deficits in the aging population and better working memory capacities in musicians, the current research findings align with earlier outcomes that music training enhances working memory abilities across age groups and may help mitigate age-related working memory decline (Maillard et al., 2023). Hence, the null hypothesis, “There is no significant difference between the working memory abilities across different age groups (10 to <20, 20 to <30, 30 to <40, 40 to <50, and 50 to <60 years) between and within musicians and non-musicians on the tests BDS and RS,” was rejected.

Objective 4: The relationship among age, psychoacoustic abilities, speech perception in noise, and working memory abilities in both musician and non-musician groups

The current study assessed the relationships between age, psychoacoustic abilities, SPiN, and working memory abilities separately in musicians and non-musicians by conducting non-parametric Principal Component Analysis (PCA) for both groups. The results revealed a significant association between SPiN (percent correct SPiN scores at +5 and 0 dB SNR), DDT, and working memory measures in non-musicians. However, psychoacoustic measures (PDT and GDT) correlated

with age and SPiN score at -5 dB SNR. In musicians, there was no correlation between SPiN and working memory measures, whereas age, SPiN scores, and GDT showed a correlation. PDT showed correlation with working memory measures. DDT did not correlate with any of the measures.

Dryden et al. (2017), in their systematic review and meta-analysis, found a weak correlation ($r = 0.28$) between working memory and SPiN measures in adults with normal to moderate hearing loss, with variability across studies highlighting the need for standardization and uniformity of procedures. Davidson and Souza (2024) reported a correlation between working memory and SPiN, which was also observed in the current study among non-musicians. Hennessy et al. (2022) noted that inconsistent cognitive measures limit conclusions about the role of working memory in SPiN. While research on music training and aging is gaining momentum, lifelong training appears to support auditory and cognitive functions, including working memory, temporal resolution, and SPiN in later life, as suggested by a few earlier studies (Parbery-Clark et al., 2011; Zendel & Alain, 2012).

Some studies in musicians found SPiN to be linked with non-verbal intelligence quotient (Boebinger et al., 2015) and working memory (Escobar et al., 2019; Lad et al., 2024; Vanden Bosch der Nederlanden et al., 2020), while others reported no significant associations (Du & Zatorre, 2017; Madsen et al., 2017; Nuesse et al., 2018; Ruggles et al., 2014; Slater & Kraus, 2016; Yeend et al., 2017). Kumar et al. (2021) found no such correlation in children with auditory processing disorder, though SPiN training improved both cognitive and auditory skills. Füllgrabe and Rosen (2016) also reported a weak association between working memory and SPiN ($r = 0.12$). Some suggest that musicians' SPiN advantage stems

more from pitch perception and temporal resolution than from cognitive skills (Frisina & Frisina, 1997; Fuller et al., 2014; Fullgrabe et al., 2015), a finding noted in the present study among musicians.

Recent studies have continued to yield mixed results. Castleberry et al. (2025) linked auditory working memory, SPiN, and music training, aligning with significant associations in younger adults (Yoo & Bidelman, 2019). Hennessy et al. (2022) argued that musical aptitude, rather than cognition, may explain the benefits of SPiN in musicians. Others emphasized rhythm (Slater & Kraus, 2016) or pitch discrimination (Meha-Bettison et al., 2018). Overall, SPiN involves both top-down cognitive processes and bottom-up auditory encoding (Anderson & Kraus, 2010; Du et al., 2011).

Research shows aging more strongly affects SPiN with speech maskers than with noise maskers (Goossens et al., 2017; Rajan & Cainer, 2008; Taitelbaum-Swead & Fostick, 2016; Tun & Wingfield, 1999), likely due to the higher cognitive demands of speech maskers (Brungart, 2001; Freyman et al., 2004; Meister et al., 2011). Grassi et al. (2017) found no significant link between perceptual (pitch, duration discrimination) and cognitive (working memory) measures in either musicians or non-musicians. While auditory working memory may contribute to musicians' SPiN advantage, its role remains unclear and requires further study (Strait et al., 2012; Yoo & Bidelman, 2019). To better understand the cognition-SPiN relationship, future research should systematically explore various cognitive domains and SPiN tasks, even where strong correlations are not expected (Dryden et al., 2017).

Coffey et al. (2017) reviewed evidence on musicians' advantages in SPiN perception compared to non-musicians. Proposed mechanisms included enhanced bottom-up encoding of pitch, harmonics, and timing (Bidelman & Alain, 2015; Pantev & Herholz, 2011), as well as top-down contributions from attention, working memory, and executive functions (Herholz & Zatorre, 2012; Moreno & Bidelman, 2014). However, mixed findings on contributing mechanisms underscored the need for task-specific approaches, longitudinal training studies (Alain et al., 2014), and research across more diverse populations. Such insights could inform clinically guided therapeutic approaches for SPiN difficulties in older adults and individuals with language disorders.

Thus, musicians consistently outperform non-musicians on psychoacoustic, SPiN, and working memory tasks, likely due to their ongoing training in detecting subtle acoustic features. This training may fine-tune the auditory system both anatomically and physiologically, enhancing its efficiency in processing complex sound environments (Chasin, 2003). These enhancements can also extend to speech perception (Besson et al., 2011). As a result, music training may improve temporal resolution and auditory discrimination, as well as working memory, particularly in older adults, which supports better speech comprehension (Besson et al., 2011; Glasberg & Moore, 1989).

Thus, the null hypothesis, "There is no significant correlation between age, psychoacoustic abilities, speech perception in noise, and working memory abilities between musician and non-musician groups," was rejected.

CHAPTER 6

SUMMARY AND CONCLUSIONS

The current study investigated the influence of aging on psychoacoustic, Speech Perception in Noise (SPiN), and working memory abilities in musicians and non-musicians across an age continuum. The study also assessed the effect of music training by comparing the performances of musicians and non-musicians on these domains. In addition, the current study evaluated the association between age, psychoacoustic abilities, SPiN, and working memory in musicians and non-musicians. To accomplish this, 181 participants (N=181) were included in the study. Out of these, 90 were non-musicians and 91 were musicians. The musicians were trained in Carnatic classical music for a minimum period of 5 years.

Psychoacoustic tests, namely the pitch discrimination test, duration discrimination test, and gap detection tests, were administered using the maximum likelihood procedure toolbox implemented in MATLAB software. Pitch discrimination threshold (PDT), duration discrimination threshold (DDT), and gap detection threshold (GDT) were determined by the software. SPiN was assessed using the Kannada sentence identification test (Geetha et al., 2014), which was mixed with four talker babble conditions at signal-to-noise ratios of +5, 0, and -5 dB. Percent correct SPiN scores were calculated. Working memory tests, namely the Backward Digit Span (BDS) and Reading Span (RS) tests, were administered using the Smriti-Shravan software.

The results of the present study can be summarized as follows:

1. Non-musicians showed an age-related decline in PDT starting from the 40 to <50 year age group, whereas musicians exhibited no such deterioration. Across all age groups, musicians outperformed non-musicians on PDT.
2. Non-musicians demonstrated an age-related decline in DDT performance in the 40 to <50 year group, while musicians showed no age effect. Musicians performed better than non-musicians within this age range.
3. Age-related effects on GDT were observed in non-musicians beginning from 40 to <50 years, and in musicians at 50 to <60 years. Musicians outperformed non-musicians in the 50 to <60 year age group.
4. Non-musicians exhibited age-related effects from the 40 to <50 year group at lower signal-to-noise ratios (0 and -5 dB), whereas musicians showed age effects only at 50 to <60 year age group. Musicians performed significantly better than non-musicians across all age groups and signal-to-noise ratio conditions.
5. Non-musicians showed a significant age-related decline on the BDS test beginning from the 40 to <50 year group, while musicians showed no such decline. Musicians performed significantly better than non-musicians from the 30 to <40 year age group onwards.
6. Non-musicians showed a non-significant age-related decline; thus, neither group exhibited a clear age-linked deterioration on the RS test. However, musicians performed significantly better than non-musicians starting from the 20- to < 30-year age group.
7. To examine the relationships among age, psychoacoustic, SPiN, and working memory abilities, a non-parametric Principal Component Analysis was conducted separately for musicians and non-musicians. In non-musicians,

significant correlations were observed between percent correct SPiN scores (0 and +5 dB SNR), working memory measures, and DDT, as well as between age and psychoacoustic measures (PDT and GDT) and percent correct SPiN score (-5 dB SNR). In musicians, no correlation was found between SPiN and working memory measures; however, significant associations were observed between age, percent-correct SPiN scores, and GDT, as well as between PDT and working memory measures.

The current research findings align with earlier studies that have demonstrated a correlation between SPiN and cognition in non-musicians (Davidson & Souza, 2024). However, in musicians, cognition showed no correlation with SPiN. The variability in results reflects the differences in participant and stimulus characteristics, as well as the inclusion criteria for musicians. Additionally, the type of music (Western vs. Carnatic), the tests used, and the procedure followed, as well as participants' equivalence in other factors such as intelligence quotient and socio-economic status, contribute to the heterogeneity of these findings. To conclude, musical training enhances psychoacoustic, SPiN, and working memory abilities, at least in middle-aged to older adults. Furthermore, sustained musical engagement may be associated with a delayed onset of age-related declines in these domains.

Implications and Future Directions

- Since musicians surpass non-musicians' performances at specific age groups on perceptual, SPiN, and working memory domains, they may show positive effects on the academic performances of children and adolescents at those ages. This

advantage, in turn, could lead to better job & career prospects when they reach adulthood.

- This study allows us to draw inferences on the developmental trajectories between musician and non-musician groups from young to older age ranges, indicating better performance graphs of auditory processing abilities in musicians compared to non-musicians, at least in the middle to older age groups

- A marked difference was reported between the musician and the non-musician group in the older population in terms of auditory and speech perception, and cognition in this study. Hence, music training or music therapy may be investigated for aging individuals with Alzheimer's or individuals with Dementia. Additionally, to enhance SPiN abilities in aging individuals, remediation methods using music may be devised.

- Lifelong musical engagement may build cognitive reserve, delaying the onset of age-related auditory and cognitive decline.

- Use of music training as a part of a therapeutic approach to the hearing impaired who are using hearing aids or Cochlear Implants, or for individuals with central auditory processing disorders, may be investigated.

- For comprehensive treatments in senior centers and retirement communities, community-based interventions are especially suitable. Due to the way music adapts to group performances, it would seem that music is an especially suitable training program for such situations, and suitable recommendations can be made (Kraus & White-Schwoch, 2014).

- Future research can explore the optimal age of initiation and duration of music training needed to achieve desired therapeutic outcomes across different domains.

- Music perception research could help design algorithms in hearing aids and CIs that better preserve fine timing and pitch cues, improving both music and speech perception.

- Electrophysiological assessment across an age continuum on various domains will help validate the findings of the current study.

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APPENDIX 1

Document of Ethical Clearance Certificate issued by the AIISH Ethical Committee

 All India Institute of Speech and Hearing (An autonomous Institute under the Ministry of Health and Family Welfare, Govt. of India) Center of Excellence - Assessed & accredited by NAAC with 'A' Grade ISO 9001: 2015 Implemented Institute Manasagangothri, Mysuru - 570 006		ಅಖಿಲ ಭಾರತ ವಾಕ್ ಶ್ರವಣ ಸಂಸ್ಥೆ ಮನಸಂಗೋತ್ರಿ, ಮೈಸೂರು - 570 006 अखिल भारतीय वाक् श्रवण संस्थान मानसगंगोत्री, मैसूर - 570 006
ETHICS COMMITTEE APPROVAL FOR BIO-BEHAVIOURAL RESEARCH PROJECTS INVOLVING HUMAN SUBJECTS AT AIISH		
AIISH ETHICS Committee (AEC)		
No. SH/EC/PhD/AUD-4/2023-2024		Dated: 22.09.2023
Title of the Thesis	: Effect of Age on Psychoacoustic Abilities, Speech Perception in Noise, and Auditory Cognitive Abilities in Musicians and Non-Musicians	
Name of the Candidate	: Ms. Kruthika. S.	
Name of the Guide	: Dr. Ajith Kumar U	
Proposed Duration of the Research Study	: 3 to 5 years	
Source of funding	: Nil	
Estimated budget	: Nil	
Reference Number of the Proposal	: ORDER NO. DOR.9.1/Ph.D/KS/PR30/2022-23 DATED:20-04-2022. Provisional Reg. No. WF-30/2022-23	
Date on which the AEC meeting was held	: 20.09.2023	
A clear statement of the decision reached AEC meeting (in the vent of the proposal is not approved, a statement of reasons for the same must be indicated	: APPROVED	
Advice & suggestions (if any)	: Nil	
Date: 20.09.2023	 Signature & Name of the Member Secretary Dr. Animesh Barman Member Secretary Professor of Audiology AIISH ETHICS Department of Audiology COMMITTEE All India Institute of Speech and Hearing, Mysore-570006	
Phone : 0821-2502000 / 2502100 Toll Free No. 18004255218 Fax : 0821-2510515, e-mail : director@aiishmysore.in / @aiishmysuruofficial, @aiishmysuru website : www.aiishmysore.in		

Table A1: Descriptives (Mean and one SD) of Mini-PROMS total score in musicians and non-musicians across different age groups

Age Groups (in years)		Mini- PROMS total score	
		Mean	SD
10 to <20	M	21.52	3.15
	NM	13.28	2.67
20 to <30	M	24.39	3.28
	NM	13.11	2.74
30 to <40	M	24.47	2.75
	NM	16.84	3.72
40 to <50	M	24.93	4.64
	NM	11.76	3.02
50 to <60	M	23.52	2.73
	NM	15.70	4.85

Table A2: Results of the Mann-Whitney U test on Mini-PROMS total scores in musicians and non-musicians in each age group tested.

Age Groups (in years)	Test Statistic (Z)	Corrected 'p'
10 to <20	4.823	<0.005**
20 to <30	5.421	<0.005**
30 to <40	0.243	<0.005**
40 to <50	1.063	<0.005**
50 to <60	0.397	<0.005**

NOTE: |Z|-test statistic, p-significance level, Corrected p-value= (obtained p-value) *(number of pairwise comparisons made). If corrected p>1.000, the value is approximated to 1.000. **-sig. level at 0.01.

Table A3: Descriptives (Mean and one SD) of ELMEQ mean score in musicians and non-musicians across different age groups

Age Groups		ELMEQ Mean score	
(in years)		Mean	SD
10 to <20	M	18.54	0.49
	NM	8.57	0.49
20 to <30	M	18.79	0.66
	NM	8.59	0.62
30 to <40	M	19.04	0.69
	NM	8.53	0.51
40 to <50	M	18.90	0.63
	NM	8.65	0.44
50 to <60	M	19.04	0.56
	NM	8.78	0.35

Table A4: Results of the Mann-Whitney U-test on ELMEQ Mean scores in musicians and non-musicians in each age group tested.

Age Groups (in years)	Test Statistic (Z)	Corrected 'p'
10 to <20	5.142	<0.005**
20 to <30	5.503	<0.005**
30 to <40	4.986	<0.005**
40 to <50	4.698	<0.005**
50 to <60	5.350	<0.005**

NOTE: |z|-test statistic, p-significance level, Corrected p-value= (obtained p-value) *(number of pairwise comparisons made). If corrected p>1.000, the value is approximated to 1.000. **-sig. level at 0.01.

Table A5: Table showing the Descriptives [Mean and one Standard Deviation (SD)] for the pure tone thresholds in both right and left ears across different octave frequencies in Musicians (M) and Non-musicians (NM) across different age groups.

Age Groups		250 Hz		500 Hz		1000 Hz		2000 Hz		4000 Hz		8000 Hz	
(in yrs)		Rt ear	Lt ear	Rt ear	Lt ear	Rt ear	Lt ear	Rt ear	Lt ear	Rt ear	Lt ear	Rt ear	Lt ear
		Mean, SD	Mean, SD	Mean, SD	Mean, SD	Mean, SD	Mean, SD	Mean, SD	Mean, SD	Mean, SD	Mean, SD	Mean, SD	Mean, SD
10 to <20	M	4.58, 1.31	4.79, 1.26	4.50, 1.39	4.58, 2.05	5.11, 1.50	5.08, 2.08	6.32, 2.48	6.29, 1.87	6.76, 3.31	6.38, 2.34	8.32, 2.49	8.41, 1.96
	NM	4.32, 1.30	4.31, 1.38	4.26, 1.32	4.55, 2.18	4.84, 1.54	5.02, 2.27	6.13, 2.27	5.94, 2.30	6.50, 3.25	6.21, 2.39	8.02, 2.44	8.47, 1.78
20 to <30	M	3.95, 0.84	4.60, 1.34	4.39, 1.35	4.70, 1.90	5.10, 1.46	5.22, 1.83	6.39, 1.60	6.39, 1.70	6.72, 2.26	6.75, 2.12	8.54, 1.96	9.04, 2.16
	NM	4.08, 0.87	4.23, 1.38	4.27, 1.35	4.27, 1.86	4.80, 1.53	4.80, 1.84	6.16, 1.76	5.94, 1.77	6.25, 2.32	6.19, 2.08	7.91, 2.11	8.13, 1.75
30 to <40	M	4.50, 1.07	4.38, 1.52	4.69, 1.52	4.38, 1.46	5.36, 1.56	4.91, 1.52	6.55, 1.89	6.16, 1.24	7.27, 2.91	6.52, 1.26	7.27, 2.91	8.25, 1.29
	NM	4.21, 0.68	4.75, 1.29	4.31, 1.18	4.62, 1.88	4.75, 1.25	5.12, 1.92	6.09, 1.59	6.40, 1.72	6.21, 2.22	6.71, 1.99	7.43, 1.73	8.34, 1.71
40 to <50	M	5.56, 2.02	5.46, 1.91	6.36, 3.14	5.96, 2.74	7.00, 2.97	6.60, 2.71	8.13, 2.66	7.90, 2.33	8.43, 3.19	7.93, 2.95	9.43, 2.76	9.26, 2.63
	NM	5.70, 1.54	5.60, 1.93	6.26, 2.08	6.33, 2.71	7.26, 1.74	7.10, 2.61	8.66, 2.11	8.20, 2.41	9.73, 3.14	8.83, 2.83	10.53, 2.27	9.83, 2.53
50 to <60	M	7.97, 2.03	7.44, 2.44	9.82, 3.20	8.91, 3.94	10.11, 3.04	9.23, 3.73	10.91, 2.76	10.32, 3.13	11.55, 2.57	10.58, 3.27	12.50, 2.33	11.64, 3.07
	NM	7.15, 1.97	6.70, 2.12	8.72, 3.01	8.04, 3.22	9.25, 2.91	8.86, 2.94	10.11, 2.79	9.63, 2.82	10.81, 2.97	10.22, 2.82	12.20, 2.87	11.54, 2.70

Table A6: Table showing the Descriptives [Mean and one SD] of TEOAE amplitude for right and left ears in Musicians (M) and Non-Musicians (NM) across different age groups

Age Groups	Group	TEOAE Amplitude Right ear		TEOAE Amplitude Left ear	
		Mean	SD	Mean	SD
10 to <20	M	16.53	3.79	15.60	3.19
	NM	15.97	3.65	15.70	4.54
20 to <30	M	13.89	2.76	13.31	2.75
	NM	13.27	2.89	13.06	2.17
30 to <40	M	11.61	3.18	11.75	3.02
	NM	11.56	3.00	11.33	3.01
40 to <50	M	9.35	2.07	9.22	1.67
	NM	9.93	2.33	9.96	2.39
50 to <60	M	7.21	0.96	7.07	0.77
	NM	7.49	0.96	7.32	1.08

Table A7: Descriptives (Mean and one SD) of WHO QOL Bref mean score in musicians and non-musicians across different age groups

Age Groups		WHO QOL Bref Mean score	
(in years)		Mean	SD
10 to <20	M	76.74	3.63
	NM	77.27	3.88
20 to <30	M	78.44	4.50
	NM	78.45	2.09
30 to <40	M	78.24	2.28
	NM	78.65	2.29
40 to <50	M	77.91	2.17
	NM	78.62	1.98
50 to <60	M	76.66	3.96
	NM	76.25	3.43

Table A8: Results of the Mann-Whitney U test on WHO QOL Bref Mean scores in musicians and non-musicians in each age group tested.

Age Groups (in years)	Test Statistic (Z)	Corrected 'p'
10 to <20	0.301	1.000
20 to <30	0.102	1.000
30 to <40	0.243	1.000
40 to <50	1.063	1.000
50 to <60	0.397	1.000

NOTE: |Z|-test statistic, p-significance level, Corrected p-value= (obtained p-value) *(number of pairwise comparisons made). If corrected p>1.000, the value is approximated to 1.000.

Kannada Sentence Lists used in Kannada Sentence Identification test (Geetha et al., 2014)

Sentence list 1 at +5 dB SNR

1	ಅವನು ತನ್ನ ಗೆಳೆಯನಿಗೆ ಸಹಾಯ ಮಾಡಿದ.
2	ರಾಜನಿಗೆ ಪ್ರಜೆಗಳು ಮನವಿ ಸಲ್ಲಿಸಿದರು.
3	ವರ್ಷಕ್ಕೆ ಒಮ್ಮೆ ನಾವು ಕಂದಾಯ ಕಟ್ಟುತ್ತೇವೆ.
4	ನಾವು ಸದಾ ಪರಿಶುದ್ಧ ನೀರನ್ನು ಸೇವಿಸಬೇಕು.
5	ರೈತ ಬಿಸಿಲಿನಲ್ಲಿ ಕೆಲಸ ಮಾಡುತ್ತಿದ್ದಾನೆ.
6	ಮಕ್ಕಳು ಸಾಲಾಗಿ ನಿಂತು ಪ್ರಾರ್ಥನೆ ಮಾಡಿದರು.
7	ರೈಲೊಂದು ಸೇತುವೆಯ ಮೇಲೆ ಚಲಿಸುತ್ತಿದೆ.
8	ಮಗು ಮಲಗಿರುವಾಗ ಹತ್ತಿರ ಹೋಗಬೇಡ.
9	ಊರಿನ ಪಕ್ಕದಲ್ಲಿ ದಟ್ಟವಾದ ಅರಣ್ಯವಿದೆ.
10	ಅವಳು ಗಾಜಿನ ಬಳಿಯನ್ನು ಹುಡುಕುತ್ತಿದ್ದಾಳೆ.

Sentence list 2 at +5 dB SNR

1	ನದಿಯ ದಡದ ಮೇಲೆ ಮೊಸಳೆ ಮಲಗಿತ್ತು.
2	ಅವನು ರೈಲಿನಲ್ಲಿ ಕಡಲೆಕಾಯಿ ಮಾರುತ್ತಿದ್ದ.
3	ಹೊಸ ಅಧಿಕಾರಿಗೆ ಹೂ ನೀಡಿ ಸ್ವಾಗತಿಸಿದೆವು.
4	ಮಳೆ ಬಾರದ ಕಾರಣ ಬೆಳೆ ನಾಶವಾಗುತ್ತಿದೆ.
5	ಅಕ್ಕನ ಮದುವೆ ಉಟ ಭರ್ಜರಿಯಾಗಿತ್ತು.
6	ಇಲ್ಲಿ ಆಡುತ್ತಿರುವ ಮಗು ನನ್ನ ಸ್ನೇಹಿತನದು.
7	ಪಾರಿವಾಳ ಬೇಟೆಗಾರನ ಬಲೆಗೆ ಸಿಕ್ಕಿಬಿತ್ತು.
8	ಮಗುವಿನ ಜಾಣ್ಮೆಯನ್ನು ಕಂಡು ಆಶ್ಚರ್ಯವಾಯಿತು.
9	ಕಪ್ಪು ದ್ರಾಕಿ ತಿನ್ನಲು ತುಂಬಾ ಹುಳಿಯಾಗಿದೆ.

10 ನದಿಯ ನೀರು ಕೊನೆಗೆ ಸಾಗರ ಸೇರುತ್ತದೆ.

Sentence list 1 at 0 dB SNR

1 ಅಪ್ಪ ತಂದೆ ಮಾವಿನ ಹಣ್ಣುಗಳು ಹುಳಿಯಾಗಿವೆ.

2 ಅವನು ಮನೆಯಲ್ಲಿ ಒಬ್ಬನೇ ವಾಸವಾಗಿದ್ದ.

3 ಮೋಡಗಳ ಹಿಂದೆ ಚಂದ್ರನು ಮರೆಯಾಗಿದ್ದಾನೆ.

4 ಹಾಲಿನಿಂದ ಸಿಹಿ ತಿನಿಸುಗಳನ್ನು ಮಾಡುತ್ತಾರೆ.

5 ರೈತರ ಬದುಕು ಇಂದು ಕಷ್ಟಕರವಾಗಿದೆ.

6 ಅವಳು ಜಡೆಗೆ ಮಲ್ಲಿಗೆ ಹೂ ಮುಡಿದಿದ್ದಾಳೆ.

7 ಶಾಲೆಗೆ ಒಂದು ವಾರ ರಜೆ ನೀಡಲಾಗಿದೆ.

8 ಬೆಂಕಿಯ ಜೊತೆ ಆಡುವುದು ಅಪಾಯಕಾರಿ.

9 ಅವನು ಕೈ ಗಡಿಯಾರದಲ್ಲಿ ಸಮಯ ನೋಡಿದ.

10 ನಾನು ವಾರಕ್ಕೊಮ್ಮೆ ಉಗುರು ಕತ್ತರಿಸುತ್ತೇನೆ.

Sentence list 2 at 0 dB SNR

1 ಅವನು ಮರ ಹತ್ತುವಾಗ ಕೊಂಬೆ ಮುರಿಯಿತು

2 ಬೇಸಿಗೆಯಲ್ಲಿ ನದಿಗಳು ಬತ್ತಿ ಹೋದವು.

3 ಸಭೆಯಲ್ಲಿ ಚರ್ಚೆಗಳು ನಡೆಯುತ್ತಲೇ ಇದೆ.

4 ಮಕ್ಕಳ ಸಂಗೀತ ಸ್ಪರ್ಧೆಯು ಎಲ್ಲರನ್ನೂ ರಂಜಿಸಿತು.

5 ಪ್ರತಿ ವಾರ ತಂದೆಗೆ ಕಾಗದ ಬರೆಯುತ್ತಿದ್ದೆ.

6 ಹಬ್ಬಕ್ಕೆ ಗೆಳೆಯರನ್ನು ಉಟಕ್ಕೆ ಕರೆದೆ.

7 ಅಮ್ಮನ ಜೊತೆ ದೂರವಾಣಿಯಲ್ಲಿ ಮಾತನಾಡಿದೆ.

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|---|-----------------------------|
| 8 | ಆ ಘಟನೆ ನಡೆದು ಶತಮಾನ ಕಳೆಯಿತು. |
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| 9 | ಶಾಲಾ ವಿಧ್ಯಾರ್ಥಿಗಳು ಪ್ರವಾಸ ಕೈಗೊಂಡರು. |
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| 10 | ರೈತನೊಬ್ಬ ಎರೆಡು ಎತ್ತುಗಳನ್ನು ಸಾಕಿದ್ದನು. |
|----|---------------------------------------|
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Sentence list 1 at -5 dB SNR

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|---|--------------------------------|
| 1 | ಹುಲಿಯ ಚರ್ಮಕ್ಕೆ ಬಹಳ ಬೇಡಿಕೆ ಇದೆ. |
|---|--------------------------------|
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| 2 | ಅಣ್ಣನು ತಂಗಿಗೆ ಸಮಾಧಾನ ಮಾಡಿದನು. |
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| 3 | ಅವರ ಅದ್ಭುತ ಆಟ ಮರೆಯುವಂತಿಲ್ಲ. |
|---|-----------------------------|
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| 4 | ಅಪ್ಪ ಗಾಡಿ ನಿಲ್ಲಿಸಿ ತರಕಾರಿ ಕೊಂಡರು. |
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| 5 | ಪೋಲೀಸರು ಜನರ ಗುಂಪನ್ನು ಚದುರಿಸಿದರು. |
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| 6 | ಮನೆಯವರೆಲ್ಲಾ ಹೋಗಿ ಸಿನಿಮಾ ವೀಕ್ಷಿಸಿದರು. |
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|---|-------------------------------------|
| 7 | ಮಗುವು ಪಟಾಕಿ ಶಬ್ದ ಕೇಳಿ ಗಾಬರಿಗೊಂಡಿತು. |
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|---|----------------------------|
| 8 | ಯುದ್ಧ ನಡೆಯಲು ಕಾರಣಗಳು ಹಲವು. |
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|---|----------------------------------|
| 9 | ಗ್ರಾಮದ ಜನತೆ ನೀರಿಲ್ಲದೆ ಕಂಗಾಲಾದರು. |
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|----|---------------------------------|
| 10 | ಅವಳು ಕಮಲದ ಹೂವನ್ನು ಪೂಜೆಗೆ ತಂದಳು. |
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Sentence list 2 at -5 dB SNR

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| 1 | ಹಸಿದ ಬೆಕ್ಕೊಂದು ಇಲಿಯನ್ನು ಹಿಡಿದು ತಿಂದಿತು. |
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|---|--------------------------------------|
| 2 | ಅಲ್ಲಿ ದೊಡ್ಡದಾದೊಂದು ಸರೋವರ ಕಾಣುತ್ತಿದೆ. |
|---|--------------------------------------|
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|---|--------------------------------|
| 3 | ಅವಳು ಕಛೇರಿಗೆಲ್ಲಾ ಸಿಹಿ ಹಂಚಿದಳು. |
|---|--------------------------------|
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- | | |
|---|------------------------------------|
| 4 | ಅಪರಾಧಿಗೆ ಜೀವಾವಧಿ ಶಿಕ್ಷೆ ವಿಧಿಸಿದರು. |
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|---|------------------------------|
| 5 | ಅರಮನೆಯ ವೈಭವ ಅಚ್ಚರಿ ಮೂಡಿಸಿತು. |
|---|------------------------------|
-
- | | |
|---|------------------------------|
| 6 | ನಾವು ಹಿರಿಯರಿಗೆ ಗೌರವ ಕೊಡಬೇಕು. |
|---|------------------------------|
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7	ತಮ್ಮನಿಗೆ ಗಾಳೀಪಟ ಹಾರಿಸಲು ಇಷ್ಟ.
8	ಉರಿನ ಜನ ಕಳ್ಳರನ್ನು ಸೆರೆ ಹಿಡಿದರು.
9	ಇವರು ಈ ಕಾಲೇಜಿನ ಹೊಸ ಅಧ್ಯಾಪಕಿ.
10	ಮಾವುತನು ಆನೆಗೆ ಸ್ನಾನ ಮಾಡಿಸುತ್ತಿದ್ದಾನೆ.

APPENDIX 2

Tables A9- A13 show Shapiro-Wilk Normality test results with the test statistic and significance levels for all the parameters studied in each age group separately.

(Note: PDT- Pitch Discrimination Threshold, DDT- Duration Discrimination Threshold, GDT- Gap Detection Threshold, SPiN- Speech Perception in Noise, BDS- Backward Digit Span, RS- Reading Span)

Table A9

	Parameters Studied	Non-Musicians		Musicians	
		Test Statistic (df=19)	Significance Level (p)	Test Statistic (df=17)	Significance Level (p)
10 to <20 years	PDT	0.890	0.033	0.829	0.005
	DDT	0.950	0.389	0.946	0.399
	GDT	0.983	0.968	0.974	0.890
	% Correct SPiN scores (+5 dB SNR)	0.782	0.001	0.833	0.006
	% Correct SPiN scores (0 dB SNR)	0.821	0.002	0.880	0.032
	% Correct SPiN scores (-5 dB SNR)	0.937	0.237	0.855	0.013
	BDS score	0.918	0.103	0.893	0.052
	RS score	0.913	0.085	0.720	0.000

Table A10

	Parameters Studied	Non-Musicians		Musicians	
		Test Statistic (df=19)	Significance Level (p)	Test Statistic (df=17)	Significance Level (p)
20 to <30 years	PDT	0.869	0.017	0.865	0.004
	DDT	0.960	0.610	0.900	0.022
	GDT	0.931	0.201	0.964	0.521
	% Correct SPiN scores (+5 dB SNR)	0.937	0.001	0.795	0.000
	% Correct SPiN scores (0 dB SNR)	0.952	0.002	0.927	0.083
	% Correct SPiN scores (-5 dB SNR)	0.939	0.237	0.935	0.126
	BDS score	0.889	0.103	0.895	0.017
	RS score	0.903	0.085	0.873	0.006

Table A11

	Parameters Studied	Non-Musicians		Musicians	
		Test Statistic (df=19)	Significance Level (p)	Test Statistic (df=17)	Significance Level (p)
30 to <40 years	PDT	0.875	0.032	0.887	0.035
	DDT	0.958	0.633	0.976	0.906
	GDT	0.921	0.175	0.960	0.597
	% Correct SPiN scores (+5 dB SNR)	0.889	0.053	0.836	0.005
	% Correct SPiN scores (0 dB SNR)	0.957	0.613	0.816	0.003
	% Correct SPiN scores (-5 dB SNR)	0.846	0.012	0.897	0.051
	BDS score	0.883	0.043	0.878	0.024
	RS score	0.927	0.220	0.648	0.000

Table A12

	Parameters Studied	Non-Musicians		Musicians	
		Test Statistic (df=19)	Significance Level (p)	Test Statistic (df=17)	Significance Level (p)
40 to <50 years	PDT	0.932	.289	0.932	0.289
	DDT	0.978	.951	0.978	0.951
	GDT	0.927	.242	0.927	0.242
	% Correct SPiN scores (+5 dB SNR)	0.943	.424	0.943	0.424
	% Correct SPiN scores (0 dB SNR)	0.898	.089	0.898	0.089
	% Correct SPiN scores (-5 dB SNR)	0.783	.002	0.783	0.002
	BDS score	.898	0.088	0.923	0.214
	RS score	.822	0.007	0.830	0.009

Table A13

	Parameters Studied	Non-Musicians		Musicians	
		Test Statistic (df=19)	Significance Level (p)	Test Statistic (df=17)	Significance Level (p)
50 to <60 years	PDT	0.890	0.019	0.862	0.017
	DDT	0.946	0.262	0.939	0.308
	GDT	0.885	0.015	0.969	0.794
	% Correct SPiN scores (+5 dB SNR)	0.957	0.423	0.798	0.002
	% Correct SPiN scores (0 dB SNR)	0.895	0.024	0.736	0.000
	% Correct SPiN scores (-5 dB SNR)	0.763	0.000	0.870	0.022
	BDS score	0.717	0.000	0.889	0.044
	RS score	0.947	0.272	0.782	0.001

Table A14: Post-hoc results with Bonferroni's corrections across age groups in non-musicians on PDT

Age Groups	Adjusted p-value
10 to <20 & 20 to <30	1.000
10 to <20 & 30 to <40	1.000
10 to <20 & 40 to <50	0.041*
10 to <20 & 50 to <60	0.088
20 to <30 & 30 to <40	1.000
20 to <30 & 40 to <50	0.013*
20 to <30 & 50 to <60	0.027*
30 to <40 & 40 to <50	0.900
30 to <40 & 50 to <60	1.000
40 to <50 & 50 to <60	1.000

Note. Significance at 0.05 level (adjusted for Bonferroni's multiple comparisons).
 *p- sig. at 0.05, **p- sig. at 0.01, ***p- sig. at 0.001. Corrected p-value= (obtained p-value)*(number of pairwise comparisons made). If corrected p>1.000, the value is approximated to 1.000.

Table A15: Post-hoc results with Bonferroni's corrections across age groups in non-musicians on DDT

Age Groups	Adjusted p-value
10 to <20 & 20 to <30	1.000
10 to <20 & 30 to <40	1.000
10 to <20 & 40 to <50	0.056
10 to <20 & 50 to <60	1.000
20 to <30 & 30 to <40	1.000
20 to <30 & 40 to <50	0.013*
20 to <30 & 50 to <60	0.639
30 to <40 & 40 to <50	0.037*
30 to <40 & 50 to <60	1.000
40 to <50 & 50 to <60	0.354

Note. Significance at 0.05 level (adjusted for Bonferroni's multiple comparisons).

*p- sig. at 0.05.

Table A16: Post-hoc results with Bonferroni's corrections across age groups in non-musicians on GDT

Age Groups	Adjusted p-value
10 to <20 & 20 to <30	1.000
10 to <20 & 30 to <40	1.000
10 to <20 & 40 to <50	0.104
10 to <20 & 50 to <60	<0.001***
20 to <30 & 30 to <40	0.847
20 to <30 & 40 to <50	0.017*
20 to <30 & 50 to <60	<0.001***
30 to <40 & 40 to <50	1.000
30 to <40 & 50 to <60	<0.001***
40 to <50 & 50 to <60	0.033*

Note. Significance at 0.05 level (adjusted for Bonferroni's multiple comparisons).

*p- sig. at 0.05, ***p- sig. at 0.001.

Table A17: Post-hoc results with Bonferroni's corrections across age groups in musicians on GDT

Age Groups	Adjusted p-value
10 to <20 & 20 to <30	1.000
10 to <20 & 30 to <40	1.000
10 to <20 & 40 to <50	1.000
10 to <20 & 50 to <60	<0.001***
20 to <30 & 30 to <40	1.000
20 to <30 & 40 to <50	0.231
20 to <30 & 50 to <60	<0.001***
30 to <40 & 40 to <50	0.706
30 to <40 & 50 to <60	<0.001***
40 to <50 & 50 to <60	0.002**

Note. Significance at 0.05 level (adjusted for Bonferroni's multiple comparisons).

p- sig. at 0.01, *p- sig. at 0.001.

Table A18: Post-hoc results with Bonferroni's corrections across age groups in non-musicians on BDS scores.

Age Groups	Adjusted p-value
10 to <20 & 20 to <30	1.000
10 to <20 & 30 to <40	1.000
10 to <20 & 40 to <50	0.025
10 to <20 & 50 to <60	0.008**
20 to <30 & 30 to <40	0.327
20 to <30 & 40 to <50	0.005**
20 to <30 & 50 to <60	<0.001***
30 to <40 & 40 to <50	1.000
30 to <40 & 50 to <60	1.000
40 to <50 & 50 to <60	1.000

Table A19: Descriptives (Mean and one SD) of transformed PDTs [(square root (sqrt) transformation)] in musicians and non-musicians across different age groups

Age Groups		Sqrt PDT (in Hz)	
(in years)		Mean	SD
10 to <20	M	3.68	1.40
	NM	5.85	1.43
20 to <30	M	3.47	1.01
	NM	5.62	1.74
30 to <40	M	3.19	0.88
	NM	6.51	1.59
40 to <50	M	3.20	0.68
	NM	7.51	1.48
50 to <60	M	3.16	0.72
	NM	7.22	1.79

Note. Significance at 0.05 level (adjusted for Bonferroni's multiple comparisons).
 p- sig. at 0.01, *p- sig. at 0.001.

Table A20: Descriptives (Mean and one SD) of transformed DDTs [(square root (sqrt) transformation)] in musicians and non-musicians across different age groups

Age Groups		Sqrt DDT (in ms)	
(in years)		Mean	SD
10 to <20	M	6.69	0.94
	NM	7.02	0.76
20 to <30	M	6.54	1.06
	NM	6.65	1.09
30 to <40	M	6.03	1.03
	NM	6.91	1.04
40 to <50	M	6.12	0.81
	NM	8.12	1.37
50 to <60	M	6.38	1.00
	NM	7.32	1.24

Table A21: Descriptives (Mean and one SD) of transformed GDTs [(square root (sqrt) transformation)] in musicians and non-musicians across different age groups

Age Groups		Sqrt GDT (in ms)	
(in years)		Mean	SD
10 to <20	M	1.60	0.22
	NM	1.61	0.29
20 to <30	M	1.56	0.21
	NM	1.53	0.24
30 to <40	M	1.59	0.15
	NM	1.75	0.28
40 to <50	M	1.71	0.16
	NM	1.94	0.40
50 to <60	M	1.96	0.14
	NM	2.29	0.46

Table A22: Descriptives (Mean and one SD) of transformed BDS scores [(square root (sqrt) transformation)] in musicians and non-musicians across different age groups

Age Groups		Sqrt BDS scores	
(in years)		Mean	SD
10 to <20	M	2.54	0.24
	NM	2.32	0.30
20 to <30	M	2.49	0.32
	NM	2.37	0.37
30 to <40	M	2.63	0.25
	NM	2.15	0.20
40 to <50	M	2.52	0.34
	NM	2.00	0.24
50 to <60	M	2.53	0.17
	NM	2.00	0.30

APPENDIX 3

List of conferences attended during the Ph.D. tenure

Name of the conference (Location)	Conference dates	Poster/Oral paper presentation title
15th Indian Speech- Language and Hearing Association Kerala State Branch 2023 (15th KSB ISHACON 2023) (Kozhikode, Kerala)	14/10/2023-15/10/2023	Auditory Cognitive Abilities and Speech Perception in Noise (SPIN) Abilities in Trained Carnatic Classical Musicians and Age- matched Non- Musicians: A Comparative Study
55th Annual Convention of the Indian Speech- Language and Hearing Association (55th ISHACON 2024) (Kolkata, West Bengal)	19/01/2024-21/01/2024	Effect of Age and Music Training on Psychoacoustic Abilities and Speech Perception In Noise
4 th FOCUS Conference (Mangalore)	8/11/2024-9/11/2024	1. Non-Musicians Experience Early Aging on Speech Perception in Noise Tasks Compared to Musicians 2. Effect of Age on Psychoacoustic Abilities in Musicians and Non- Musicians
Audiology Australia 2025 conference (Adelaide, Australia)	1/4/2025- 4/4/2025	Effect of Age on Auditory Cognitive and Speech Perception in Noise Abilities in Musicians and Non-Musicians

List of papers published during the Ph.D. tenure

Title of the article	Year of publishing	Journal	DOI
Nonmusicians Experience Early Aging on Working Memory Tasks Compared to Musicians	2025	Neuroregulation	https://doi.org/10.15540/nr.12.1.2
Effect of Age on Psychoacoustic Abilities in Musicians and Nonmusicians	2025	Journal of American Academy of Audiology	https://doi.org/10.3766/jaaa.240040
Non-Musicians Experience Early Aging in Speech Perception in Noise Abilities Compared to Musicians	2025	Journal of Otology	https://doi.org/10.26599/joto.2025.9540020



**15th KSB
ISHACON
Kozhikode 2023**



INDIAN SPEECH- LANGUAGE & HEARING ASSOCIATION KERALA STATE BRANCH

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CERTIFICATE

This is to certify that Prof./Dr./Mr./Ms.

Kruthika S & Ajith Kumar U

has presented a scientific Poster paper 'Auditory cognitive abilities and speech perception in noise (SPIN) Abilities in trained Carnatic classical musicians and age-matched non-musicians: a comparative study' in the 15th National Level Conference of Indian Speech Language & Hearing Association - Kerala State Branch held on 14-10-2023 & 15-10-2023 at Kozhikode. This conference is approved as CRE by Rehabilitation Council of India (RCI), a Statutory Body of the Ministry of Social Justice and Empowerment, Department of Empowerment of Persons with Disabilities (Divyangjan), Government of India, New Delhi, vide approval No. F. No. 7-16 (429)/2023, CRE 23080217568446 - RCI dated 10th August 2023 with **10 CRE points**.

**Dr. Prem G
President
ISHA-KSB**

**Mr. Jabir PIM
General Secretary
ISHA-KSB**

INDIAN SPEECH-LANGUAGE AND HEARING ASSOCIATION

(Under the Karnataka Societies Registration Act 1960. (No.17) Registration N. S25/67-68)



CERTIFICATE FOR THE SCIENTIFIC PRESENTATION

ISHA Appreciates the presentation of the scientific paper entitled

EFFECT OF AGE AND MUSIC TRAINING ON PSYCHOACOUSTIC ABILITIES AND SPEECH PERCEPTION IN NOISE

at the 55th Annual Convention of the Indian Speech-Language and Hearing Association held at
Science City, Kolkata from 19-21 January, 2024 under the category - Audiology Poster.

This paper was authored by Kruthika S & Ajith Kumar

Dr. Indranil Chatterjee
Organizing Chairperson

Ms. Meenakshi Wadhwa
Chairperson - Scientific Committee

Dr. Suman Kumar
Hon. General Secretary

Dr. Prakash Boominathan
President





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RCI & UGC recognised



CERTIFICATE OF APPRECIATION

This certificate for achievement is handed to

Kruthika Shankar & Ajith Kumar U

for the paper titled

**"NON-MUSICIANS EXPERIENCE EARLY AGING ON SPEECH PERCEPTION
IN NOISE TASKS COMPARED TO MUSICIANS"**

Presented at **FOCUS - 4** state level conference of speech and hearing
held on **8th and 9th November, 2024**, organised by
Father Muller College, Department of speech and Hearing, Mangaluru

Rev. Fr Richard Aloysius Coelho
Director, FMCI

Prof. Cynthia Samthmayor
Organising Chairperson

Dr. Prashasti P Poovaiah
Organising secretary





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CERTIFICATE
OF APPRECIATION

This certificate for achievement is handed to

Kruthika Shankar & Ajith Kumar U

for the paper titled

**"EFFECT OF AGE ON PSYCHOACOUSTIC ABILITIES IN MUSICIANS
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Prof. Cynthia Samthmayor
Organising Chairperson

Dr. Prashasti P Poovaiah
Organising secretary





AUDIOLOGY
AUSTRALIA
CONFERENCE

CERTIFICATE OF ATTENDANCE

This is to certify that

KRUTHIKA SHANKAR

Attended the 2025 Audiology Australia Conference
held between 1-4 April 2025



TOTAL NUMBER
OF HOURS:

4.5



Nonmusicians Experience Early Aging on Working Memory Tasks Compared to Musicians

Kruthika Shankar* and Ajith Kumar Uppunda

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Abstract

Background. Previous studies on musicians have revealed better working memory (WM) abilities in musicians than in nonmusicians. This study investigates whether the deterioration of WM with aging is slowed in musicians relative to nonmusicians by assessing their performances across an age continuum. **Methods.** A cross-sectional descriptive mixed design was used. The study involved 150 participants, 75 musicians, and 75 nonmusicians, with 15 musicians and 15 nonmusicians in each age group (10–19.11, 20–29.11, 30–39.11, 40–49.11, and 50–59.11). Simple and complex spans were measured to assess the participant's WM capacity. Backward Digit Span (BDS) maximum and Reading Span Percent Correct Score Weighted (RS PCSW) scores were calculated. **Results.** Two-way ANOVA revealed significant main effects of musicianship ($p < .001$) and age ($p < .05$) on BDS maximum and RS PCSW scores. A "moderate to large" effect size was noted ($\eta^2 = 0.062$ to 0.455). Interaction effects were observed for BDS maximum ($p = .022$) and approached significance for RS PCSW ($p = .06$). Post-hoc analysis revealed that age effects were exclusively present in nonmusicians. **Conclusion.** Musical training can significantly reduce the cognitive decline associated with aging. It improves WM abilities, thereby minimizing the deleterious effects of aging.

Keywords: music training; age effect; cognition; working memory; backward digit span; reading span

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Introduction

The auditory system alters as we age, both physiologically and physically. These alterations may impact different parts of the auditory system, ranging from the external auditory canal to the auditory cortex of the brain, resulting in age-related hearing impairments such as presbycusis (Howarth & Shone, 2006). Even when hearing sensitivity is adequately preserved at conventional audiometric frequencies, aging may cause a loss in perceptual and cognitive ability (Houtgast & Festen, 2008). Thus, aging is connected with a decline in cognitive skills, with working memory (WM) impairment being a significant contributing component. WM refers to the ability to maintain and process information simultaneously while performing complex tasks. Attempts to prevent WM deterioration may assist older people in improving their quality of life

(Matysiak et al., 2019). Finding ways to lessen age-related perceptual, cognitive, and neurological decline is crucial in a community that is aging. One such skill is learning music.

Research in the last decade has highlighted professional musicians' superiority in sensory, motor, and cognitive abilities compared to nonmusicians (Barrett et al., 2013; Kraus & Chandrasekaran, 2010). Music training is known to induce functional and structural brain plasticity (George & Coch, 2011; Talamini et al., 2016). Professional musicians are proven to have higher "active auditory association areas" than nonmusicians (Gaab & Schlaug, 2003). Therefore, musicians are commonly viewed as models for researching plasticity over their lifetime (Barrett et al., 2013; Kraus & Chandrasekaran, 2010). Musicians are said to outperform nonmusicians on

memory tasks (Bregman, 1990). WM is reported to be strengthened in musicians (Bregman, 1990; Martin, 2009). Nonetheless, some research indicates that musicians and nonmusicians function similarly in terms of short-term memory, WM, reasoning, or executive skills (Boebinger et al., 2015; Helmbold et al., 2005). Thus, the WM performance is somewhat better for musicians than for nonmusicians. Still, the literature is unclear regarding the former's potentially superior cognitive performances compared to the latter.

Musicians are deemed to possess greater auditory WM (Chan et al., 1998; Talamini et al., 2016) and verbal and nonverbal IQ (Schellenberg, 2006). In a previous meta-analytic study, it was noted that when the participants chosen were younger, and the stimuli were verbal or tonal, musicians outperformed nonmusicians on memory tests; however, the outcomes were different when the participants selected were adults, and the stimuli were visual and spatial (Talamini et al., 2017). In another meta-analysis, 13 studies were considered. Studies on aging musicians above 59 years of age assessed their cognitive abilities. The results indicated a clear advantage of music training in improving cognitive abilities in older adults (Román-Caballero et al., 2018).

Therefore, on cognitive tasks, age and music training have opposite impacts. According to a recent systematic review, the median age-related cognitive impairment prevalence was 19%, with a range of 5.1 to 41% in adults older than 50 years of age (Pais et al., 2020). The incidence was between 22 and 76.8%, with a median of 53.97 per 1,000 people. Because age-related processing deficits are highly prevalent and have detrimental effects on the older population, it is crucial to prevent, mitigate, or postpone them. Thus, older individuals may benefit from any effort to halt WM deterioration. Nonetheless, the literature has disagreement over the effectiveness of techniques like WM training methods (Matysiak et al., 2019).

Music is a known facilitator that causes improvements in WM abilities. Several microtonal changes are found in Carnatic music, which are absent in Western classical music (Krishnaswamy, 2004). This intrinsic microtonal emphasis in Indian music can be used to process temporal, pitch, and intensity changes in sound over different frequency channels, resulting in improved binaural and temporal resolution (Mishra et al., 2014). Until now, no study has looked at a range of ages to thoroughly examine how aging affects cognitive skills in

musicians and nonmusicians. This research will provide insight into when aging begins and when its degenerative effects manifest in musically trained and untrained groups. The results on musicianship advantage are also not definitive because a few studies have demonstrated that groups of musicians and nonmusicians perform similarly on such tasks. Thus, we investigated the WM capacities of vocalists of different ages and compared the results to cohorts of nonmusicians of similar ages.

Therefore, the current study aimed to examine the auditory cognitive capacities of musicians and nonmusicians throughout a range of ages. The goal was to investigate how age affected WM tasks in musicians and nonmusicians. Tests such as the Backward Digit Span (BDS) and reading span (RS) were administered to determine WM skills. Participants in a continuum of age ranges were assessed in the musician and nonmusician groups.

Methods

A cross-sectional descriptive study with a mixed design was carried out. Using convenient sampling, the individuals were chosen. Before the study began, all participants were informed of its purpose and objective. The participants were asked to sign an informed consent form if they were willing to participate, and signed consent was obtained before commencing data collection. The investigation complied with "All India Institute of Speech and Hearing's ethical guidelines for bio-behavioral research involving human subjects" (Venkatesan & Basavaraj, 2009).

Participants

The study evaluated 150 participants ($N = 150$), 75 musicians and 75 nonmusicians, in five age groups: 10–19.11 years, 20–29.11 years, 30–39.11 years, 40–49.11 years, and 50–59.11 years. In each age group, there were 15 musicians and 15 nonmusicians. According to Muñoz-Pradas et al. (2021) and Sluzenski et al. (2006), WM—which consists of components like the phonological loop, visuospatial sketch pad, central executive, and episodic buffer—is known to develop adult-like capacities from ages 8 to 9, 11 years, 14 to 15 years, and by six years, respectively. The BDS task, which measures WM ability, reaches adult-like maturation by 11 to 11.5 years of age (Reynolds et al., 2022), with an average BDS score of 4.2, which is comparable to that reported for adults (Gignac, 2015; Gignac & Weiss, 2015). Another study indicated that auditory processing skills matured only after age 11 (Yathiraj & Vanaja, 2015). Based

on the information from the above studies, the specified age ranges were chosen for the study.

The Mini-Mental State Examination (MMSE; Folstein et al., 1975) was used to test older individuals (aged 50 to 59.11 years) for cognitive capacities before they took part in the study. Individuals with scores higher than 24 were included in the research study. Elderly individuals who scored above 50% on the Screening Checklist for Auditory Processing in Adults (SCAP-A) were excluded from the study (Vaidyanath & Yathiraj, 2014). For the younger age group, the participants had received vocal training in Carnatic classical music for a minimum of 5 years in the youngest age group, while for the other age groups the training received was at least 10 years. The study did not include the instrumentalists.

Test Environment

All audiological evaluations took place in a calm setting with sufficient ventilation and light. To ensure that the tested sounds could be clearly heard and fairly evaluated, a "silent setting" with low background noise levels was used.

Instrumentation, Materials, and Software

Using MATLAB (version R 2014a) loaded on an HP laptop and the maximum likelihood procedure (MLP; Grassi & Soranzo, 2009), the absolute threshold test was conducted to evaluate hearing thresholds. A calibrated immittance equipment (Path Medical Sentiero) was used to conduct tympanometry and acoustic reflex tests. Transient-evoked otoacoustic emissions (TEOAEs) were recorded using the Maico Ero Scan screening otoacoustic emission (OAE) instrument. Using an HP laptop and Smriti-Shravan (Kumar & Sandeep, 2013), an institutional software with an audio-cognitive training module, the auditory cognitive WM tests were conducted. Threshold estimations and cognitive testing were performed using Sennheiser HD-569 high-fidelity headphones (Denmark, Germany). The stimulus was delivered through headphones at 70 dB SPL calibrated using SLM (Larsen and Davis Sound Advisor Model-831c-Type 1 SLM with AEC201 ear simulator with a frequency range up to 16 kHz) with the laptop volume set to deliver 70 dB SPL.

Procedure

The test was performed in two phases. In the initial phase, a brief case history was obtained. Subsequently, the MMSE and SCAP-A tests were conducted (limited to older adults aged 50–59.11 years). Basic audiological tests were also performed, including OAE, immittance, and pure tone

audiometry. The second phase involved administering cognitive tests.

The absolute threshold test was used for threshold estimation using the MLP approach. Pure tones with 10 ms cosine-squared envelopes and frequencies ranging from 250 Hz to 8 kHz were presented binaurally. The psychometric function that gives the maximum likelihood of getting the response is displayed as the next stimulus in MLP to maximize the potential of reaching the threshold with fewer trials. Binaurally delivered thirty stimuli were used to test thresholds. The yes–no method was employed, in which individuals reported hearing the sound or not. Thus, MLP was used to determine each participant's pure tone thresholds for both ears. The threshold was the mean between the level not heard and the level last heard by the participant. The thresholds were compared to the absolute threshold values of MLP obtained on 30 individuals. They were not a part of the study participant sample. They were selected through the convenience sampling method. Their hearing thresholds were within 15 dB HL at all audiometric frequencies, and their MLP thresholds were taken as a reference for comparison and threshold determination. Tympanometry was assessed using a 226 Hz probe tone frequency at 85 dB SPL and increasing pressure from –400 to +200 daPa at a rate of 200 daPa/s. Reflex testing was done at 500 and 1000 Hz.

Auditory Cognitive Tests. Cognitive capacities, notably WM, deteriorate with aging (Matysiak et al., 2019). Many cognitive tasks, such as understanding different languages, logical thinking, and solving problems, depend on WM (Vuontela et al., 2003). The BDS and RS tests from Smriti Shravan software were used in assessing musicians' and nonmusicians' auditory WM abilities as they are the most valid measures of WM capacities in humans (Conway et al., 2005).

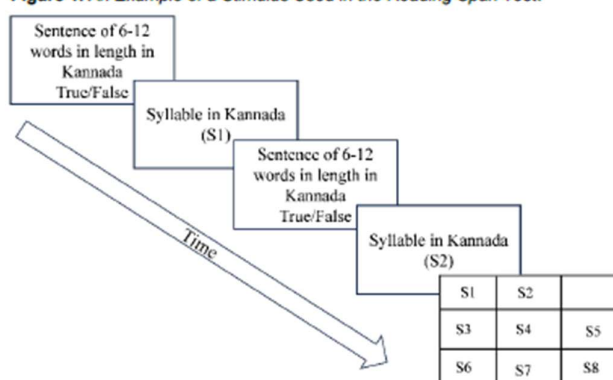
Backward Digit Span Test. Eight digitally recorded Kannada numbers (between 1 to 8, except 2) with a sampling frequency of 44.1 kHz were presented binaurally at an intensity of 70 dB SPL. The interstimulus interval was 1 s. Participants were instructed to enter them in reverse order according to how they heard the numbers. A practice trial was conducted. The test began with two digits. Following each correct response, the subsequent series of numerals included one additional digit. Each incorrect response resulted in the deduction of one of the digits from the previous sequence. This method was repeated six times. The backward span scores were calculated by taking the mean of the

last four reversal points. The BDS test's maximum score was used for analysis purposes (BDS maximum).

Reading Span Test. The RS test involved determining whether a Kannada statement was correct (secondary task) regarding meaning or logic while memorizing and recalling the bisyllabic words in Kannada (primary task) presented alternatively after each statement. Each trial had different types of primary and secondary tasks, so the participants could not estimate the difficulty level. It was investigated how accurately the participants completed the primary and secondary tasks. Each

display in the RS task displayed a statement that either was meaningful or was not meaningful, followed by a CV syllabic word. (e.g., Naukarānige varjaḍalli eradu ba:ri ma:ṭra kaṭṭe:riḡe ho:galu anumaṭi ni:ḍala:guttage followed by /tʃa:ku/). Half of the statements in the test were meaningful, while the other half were meaningless and were presented randomly. The subjects responded by saying correct or incorrect. Each trial featured two to five sentences and bisyllabic word items. Three trials of each length were presented, making around 12 trials. An example set of stimuli from the reading span test is shown in Figure 1.

Figure 1. An Example of a Stimulus Used in the Reading Span Test.



Following the presentation of all trial items, the subject was asked to recollect every word after each sentence in the order in which they occurred. Participants were tested on their ability to remember all words correctly. The Reading Span Percent Correct Score Weighted (RS PCSW) measure was calculated. This measure sums together the elements that were recalled correctly, regardless of whether the items were perfectly recalled (and does not take serial order within items into account; Conway et al., 2005). A weighted score means that all the words will have similar weightage. If the word was recalled, it received a score of one; otherwise, it received a score of zero. The average of 12 trials yielded 12 values, divided by 12, which led to the RS PCSW score. The accuracy of the secondary task was also recorded, with a minimum of 85% needed as a criterion for the analysis of the RS PCSW score (Sanchez et al., 2010).

Results

The mean and standard deviation (SD) of age and four-frequency pure tone average (PTA) for 0.5, 1, 2, and 4 kHz were calculated using descriptive statistics. Independent *t*-tests revealed no significant differences between the pure tone threshold values of musicians and nonmusician groups at octave frequencies (from 250 Hz to 8 kHz) in each age group in both ears ($p > .05$). Reflexes were present at 500 Hz and 1000 Hz in both ears in nonmusician and musician groups across different age groups. OAEs were present in both groups and across different age groups, passing the 6 dB criteria for indicating their presence. Figures 2 and 3 show the mean and SD values for pure tone thresholds for the right and left ear, respectively, for musicians and nonmusicians.

Figure 2. Mean and One SD (Error Bars) of Pure Tone Thresholds for Musicians and Nonmusicians for the Right Ear.

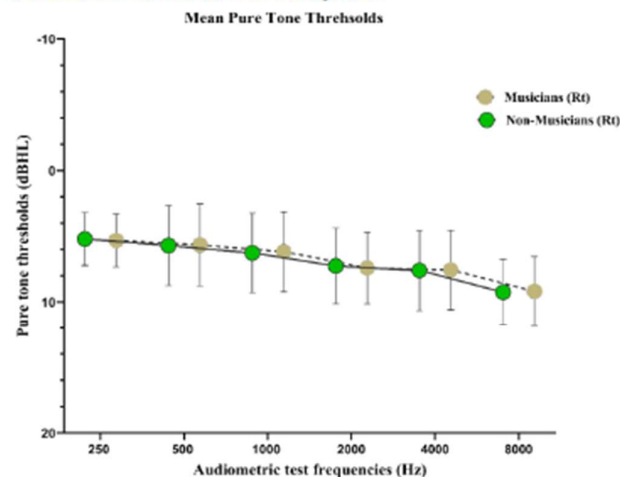
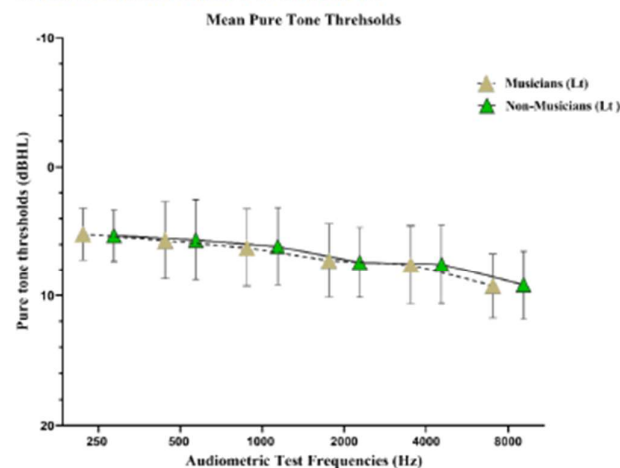


Figure 3. Mean and One SD (Error Bars) of Pure Tone Thresholds for Musicians and Nonmusicians for the Left Ear.



Similarly, descriptive statistics were performed to determine the mean and SD values of the dependent variables, namely the BDS maximum and RS PCSW scores. Shapiro Wilk's test of normality showed a bell-shaped distribution for all cognitive measures at different age groups ($p > .05$). Hence,

parametric tests were used for statistical analyses. Figures 4 and 5 show the mean and SD values of BDS maximum and RS PCSW scores, respectively, for musicians and nonmusicians across different age groups.

Figure 4. Mean and SD (Error Bars) for BDS Maximum Scores Across Different Age Groups in Musicians and Nonmusicians.

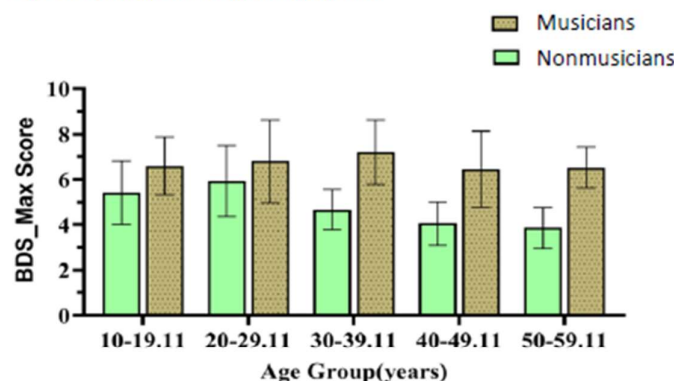
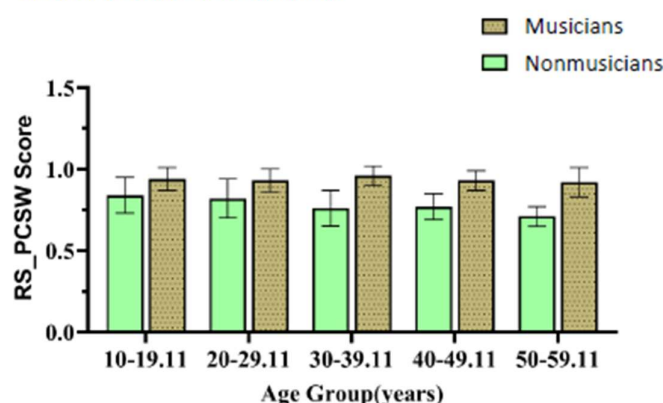


Figure 5. Mean and SD (Error Bars) for RS PCSW Scores Across Different Age Groups in Musicians and Nonmusicians.



Effect of Aging and Music Training on Auditory Cognitive Tests

Backward Digit Span Test. A two-way ANOVA (analysis of variance) was administered to assess the effects of aging and music training on BDS maximum score. Results of two-way ANOVA with musicianship and age group as the between-subject factors indicated that there was a significant musicianship effect, $F(1, 140) = 78.999$, $p = .001$, $\eta^2 = 0.361$; there was a significant age effect, $F(4, 140) = 4.280$, $p = .003$, $\eta^2 = 0.109$; and an interaction effect between musicianship and age effects, $F(4, 140) = 2.950$, $p = .022$, $\eta^2 = 0.078$.

The interaction effect is noted when the effect of one independent variable (musicianship) varies depending on the level of another independent variable (age groups). One-way ANOVA was conducted to resolve the interaction effects with age groups as the between-subject factor on nonmusicians and musicians. The test indicated a significant main effect of age groups in nonmusicians, $F(4, 70) = 8.179$, $p = .001$, $\eta^2 = 0.319$. However, there was no significant age effect in musicians, $F(4, 70) = 0.613$, $p = .654$, $\eta^2 = 0.034$. Independent t -tests were done to assess further the age effect noted in nonmusicians, and

Bonferroni's corrections were applied. Post-hoc analysis with Bonferroni's corrections for multiple comparisons indicated an effect of aging and its influence on test results only in nonmusicians. The impact of aging on this task initiates from 40–49.11

years in nonmusicians. However, there was no significant difference across different age groups among musicians. The outcomes are displayed in Table 1 below.

Table 1
Results of Independent t-Tests in Nonmusicians Across Different Age Groups on BDS Maximum Scores

Age Groups	t value	df	p-value
10–19.11 & 20–29.11	0.977	28	1.000
10–19.11 & 30–39.11	1.703	28	.500
10–19.11 & 40–49.11	3.035	28	.020
10–19.11 & 50–59.11	3.543	28	.005*
20–29.11 & 30–39.11	2.699	28	.06
20–29.11 & 40–49.11	3.910	28	.005*
20–29.11 & 50–59.11	4.384	28	< .001**
30–39.11 & 40–49.11	1.765	28	.44
30–39.11 & 50–59.11	2.414	28	.115
40–49.11 & 50–59.11	0.584	28	1.000

Note. df - degrees of freedom; p - significance level. *p < .01, **p < .001.

Reading Span Test. Results of two-way ANOVA with musicianship and age group as the between-subject factors indicated that on RS PCSW measure, a significant main effect of musicianship, $F(1, 140) = 116.760$, $p = .001$, $\eta^2 = 0.455$, and an age effect, $F(4, 140) = 3.382$, $p = .011$, $\eta^2 = 0.088$ were found; however, a significant interaction effect was not seen, $F(4, 140) = 2.320$, $p = .060$, $\eta^2 = 0.062$. Since the interaction effect approached significance levels ($p = .060$), post-hoc analysis using one-way ANOVA was carried out across age groups to deconvolute the possible interaction effect. The test results revealed that there was a significant main effect of age groups in the nonmusician group, $F(4, 70) = 4.006$, $p = .006$, $\eta^2 = 0.186$, whereas the same was not present in the musician group, $F(4, 70) = 0.705$, $p = .591$, $\eta^2 = 0.039$. Age effects in nonmusicians were analyzed using independent

t-tests. Bonferroni's corrections for multiple pair comparisons were used subsequently. The results suggested that aging degrades RS tasks only selectively in nonmusicians and that the age effects were evident in the 50–59.11-year-old age group. The outcomes are presented in Table 2 below.

A popular method to evaluate effect size in the context of ANOVA and other statistical tests is partial eta squared (η^2). After adjusting for other variables, it shows the percentage of the dependent variable's overall variability that can be attributed to a specific independent variable (Cohen, 2013; Richardson, 2011). The current study indicated a "moderate to high" effect size ($\eta^2 = 0.062$ to 0.455) on BDS maximum and RS PCSW measures, indicating the statistical significance of music training in improving cognitive capacities.

Table 2
Results of Independent T-Tests in Nonmusicians Across Different Age Groups on RS PCSW Scores

Age Groups	t value	df	p-value
10–19.11 & 20–29.11	0.357	28	1.000
10–19.11 & 30–39.11	1.875	28	.355
10–19.11 & 40–49.11	2.072	28	.24
10–19.11 & 50–59.11	3.810	28	.005*
20–29.11 & 30–39.11	1.436	28	.81
20–29.11 & 40–49.11	1.552	28	.66
20–29.11 & 50–59.11	3.158	28	.02
30–39.11 & 40–49.11	0.075	28	1.000
30–39.11 & 50–59.11	1.574	28	.635
40–49.11 & 50–59.11	2.041	28	.255

Note. df - degrees of freedom; p - significance level. *p < .01, **p < .001.

Discussion

The results of the current study indicated that musicians showed a definite advantage compared to nonmusicians on WM tasks. Also, the process of aging occurs differently in musicians and nonmusicians. Musicians remain less affected by the degenerative effects of aging on cognition.

Effect of Aging and Music Training on Auditory Cognitive Tests

Backward Digit Span Test. Results indicated that musicians did not show the consequences of aging on the BDS maximum score. However, nonmusicians showed age effects at 40–49.11 years. BDS task assesses the complex verbal task that measures the maintenance and manipulation of memorized verbal information (Owen et al., 2005). According to an earlier study, only a slight difference was noted between musicians and nonmusicians in the BDS task compared to the forward span task, owing to the complexity of the task (Hansen et al., 2013). A former study by Lee et al. (2007) concluded that children with musical training performed better than those without musical training on simple maintenance tasks like forward digit span tasks compared to more complex functions like BDS. However, in our study, musicianship had a significant advantage on a complex verbal recall task like BDS.

Similar results of musician advantage on tasks of BDS have been reported previously in the literature,

consistent with our findings, especially in adults (Zuk et al., 2014). A brief musical instrumental training program enhanced backward span performance but not forward span performance, according to Guo et al. (2018). Similar findings were discovered by Bergman Nutley et al. (2014), who showed that individuals and children with musical training fared better on BDS than their counterparts without training. BDS involves attending to the sequence of digits, forming auditory imagery and temporally sequencing the words and modifying them, similar to melody or rhythm imagery and imitation by musicians (Hansen et al., 2013). Playing or singing from memory emphasizes constantly sustaining and updating WM since it needs to match the music model stored in one's memory (Saarikivi et al., 2019). In an earlier study of WM assessment in musicians and nonmusicians, Talamini et al. (2016) found that musicians outperformed nonmusicians in their research unit of young people, regardless of the modality or complexity of digit span tasks, which is supportive of our study's results.

Reading Span Test. Results indicated that musicians did not show the effects of aging. However, nonmusicians showed age effects at 50–59.11 years. Franklin et al. (2008) compared musicians and nonmusicians to assess working and long-term memory on reading and operation span tasks. The study found that musicians outperformed nonmusicians in both tasks. The musicians in the current study might have used a sub-vocal rehearsal or sub-vocalization strategy to memorize the words,

as reasoned in a similar prior study (Hansen et al., 2013). The current findings prove that verbal rehearsal mechanisms contribute to the verbal memory advantage associated with musical competence. Improved verbal memory may be due to better auditory cortex development (Helmbold et al., 2005), increased planum temporale volume, and left hemisphere activation in verbal memory tasks (Schlaug et al., 1995). Enhanced myelination and increased grey matter volume are also linked with improved WM task performance in musicians (Munte et al., 2002). Musicians process auditory stimuli more efficiently than nonmusicians (Tervaniemi et al., 2005). Similarly, with the RS task, superior performance in the audio-visual modality can be linked to the ability of the musically-trained brain to integrate information from different sensory modalities (Talamini et al., 2016). Additionally, music training may encourage chunking and other active learning strategies. Chunking is a strategy required to commit to a tune and transfer it to musicians' memory. Thus, musicians may outperform nonmusicians in WM tests using one or more such strategies (Talamini et al., 2017).

Conclusions

Music training can significantly slow the degenerative consequences of the aging process. Furthermore, our study found that music training increases cognitive capacities in people of various ages. Engaging in musical practice or giving music therapy may help to mitigate or reduce age-related cognitive losses (Maillard et al., 2023). Additionally, music instruction may also improve academic achievement in children and adolescents. This advantage may lead to improved job and career prospects once they reach maturity. Subjective outcomes must be correlated with objective test findings over a broad age range to encourage music learning and boost music-based rehabilitation, especially in the aging population.

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Author Disclosure

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Non-Musicians Experience Early Aging in Speech Perception in Noise Abilities Compared to Musicians

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ABSTRACT

Background: Research has shown that musicians outperform non-musicians in speech perception in noise (SPiN) tasks. However, it remains unclear whether the advantages of musical training are substantial enough to slow down the decline in SPiN performance associated with aging. **Objectives:** Therefore, we assessed SPiN performances in a continuum of age groups comprising musicians and non-musicians. The goal was to compare how the aging process affected SPiN performances of musicians and non-musicians. **Method:** A cross-sectional descriptive mixed design was used, involving 150 participants divided into 75 musicians and 75 non-musicians. Each age group (10-19, 20-29, 30-39, 40-49, and 50-59) consisted of 15 musicians and 15 non-musicians. Six Kannada sentence lists were combined with four-talker babble. At +5, 0, and -5 dB signal-to-noise ratios (SNRs), the percent correct Speech Identification Scores were calculated. **Results:** The two-way repeated measure ANOVA (RM ANOVA) revealed significant main effects and interaction effects between SNR, musicianship, and age groups ($p < 0.05$). A small to large effect size was noted ($\eta_p^2 = 0.05$ to 0.17). A significant interaction effect and follow-up post hoc tests showed that SPiN abilities deteriorated more rapidly with increasing age in non-musicians compared to musicians, especially at difficult SNRs. **Conclusions:** Musicians had better SPiN abilities than non-musicians across all age groups. Also, age-related deterioration in SPiN abilities was faster in non-musicians compared to musicians.

KEYWORDS

Music training, Age effects, Speech Perception in Noise, Signal to Noise Ratio, Speech Identification Scores.

1 Introduction

Aging is a natural process that impacts the anatomical and physiological aspects of a healthy auditory system (Howarth and Shone, 2006). For the auditory system to function optimally, both peripheral and central systems must work efficiently. Despite normal hearing sensitivity at conventional audiometric frequencies, aging leads to a decline in perceptual and cognitive abilities (Betlejewski, 2006). Older individuals (>55 years) (Kim and Zakour, 2017) frequently struggle to interpret speech in noisy situations despite having preserved peripheral hearing sensitivity. The difficulty in comprehending speech may lead to reduced socialization, miscommunications, dilemmas, and inadequate standard of living (Gomez and Madey, 2001; Betlejewski, 2006). The SPiN difficulties are estimated to be prevalent in about 40% of the population above 50 years and about 71% over 70 years (Slade et al., 2020; Boncz et al., 2024). Deficits in 'selective attention' among the aging population, combined with an inability to avoid distractions from irrelevant stimuli, are particularly prevalent during informational masking occurring in cocktail party scenarios (Boncz et al., 2024).

The underlying cause of age-related difficulty in comprehending SPiN remains unclear. Various factors may contribute to these

difficulties, including peripheral and central auditory processing changes, cognitive decline, and reduced neural plasticity. Age-related auditory changes involve structural, functional, cellular, and chemical alterations. Structural changes include cochlear hair cell degeneration and auditory cortex and brainstem atrophy (Burke and Barnes, 2006). Functionally, older adults may experience difficulty hearing soft sounds, understanding speech in noise, and slower auditory processing (Anderson et al., 2011; Tun et al., 2002). Cellular changes, such as mitochondrial dysfunction and synaptic degeneration, reduced auditory sensitivity and auditory processing are noted (Someya and Prolla, 2010). Chemically, neurotransmitter imbalances and reduced inhibitory effects of GABA function further degrade temporal resolution and speech perception in noise (Caspary et al., 2008).

Cortical changes are reported to occur between the ages of 40 to 55 years (Alain et al., 2014), or at ages over 55 (Anderson et al., 2020; Dapper et al., 2025; Caspary et al., 2008). A series of studies were done by Presacco et al. (2016a, 2016b, 2019) which focused on establishing the physiological basis for SPiN difficulties in the aging population. Changes in cortical and sub-cortical areas of the brain causing temporal processing issues are known to cause SPiN problems (Presacco et al., 2016a, 2016b). Based on multi-modal

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brain imaging studies, age-linked worsening in SPiN is connected with several anatomic and physiologic alterations at the level of the brain. Challenges of older adults with SPiN are associated with thinner cortex in the areas involved in executive function (the medial frontal cortex, dorsal anterior insula, and anterior cingulate cortex), auditory and speech processing (the inferior frontal gyrus, ventral premotor cortex, and superior temporal cortex) (Tremblay et al., 2021). Additionally, a local imbalance of excitatory and inhibitory mechanisms leads to imprecise coding of complex stimuli at the midbrain and brainstem (Presacco et al., 2019). Thus, aging impairs subcortical neural processing—reducing phase-locking, synchrony, affecting auditory brainstem responses to speech-in-noise (Clinard et al., 2010; Anderson et al., 2012; Clinard and Tremblay, 2013). Declines in neural plasticity and GABA-mediated inhibition further weaken cortical noise suppression and degrade SPiN abilities (Alain et al., 2014; Caspary et al., 2008).

Musicians with lifelong musical training exhibit a noticeable advantage in comprehending speech in noise (Parbery-Clark et al., 2009a; Parbery-Clark et al., 2009b). Various auditory skills are better in musicians, like listening in the presence of reverberation (Bidelman and Krishnan, 2010), categorical speech perception (Bidelman et al., 2014), and successful stream segregation (Zendel and Alain, 2012). Musicians are shown to have cortical and subcortical brain changes secondary to music training (Strait and Kraus, 2011). Musicians have a better brainstem frequency following response amplitude for music and speech than non-musicians, indicating enhanced sub-cortical functionality (Musacchia et al., 2007). Grey matter volume was highest in the Left Cerebellum, Left Inferior Frontal Gyrus, and Left Heschl's Gyrus for professional musicians, medium in mediocre musicians, and poorest in non-musicians, according to a voxel-based study by Gaser and Schlaug (2003).

A recent meta-analysis by Hennessy et al. (2022), indicated a moderate effect size on the SPiN task, with musicians outperforming non-musicians in the 31 studies extracted. However, in prior research by Ruggles et al. (2014), a young cohort of musicians showed no evident differences compared to their non-musician counterparts. Similar findings were reported by a few other authors as well (Swaminathan et al., 2015; Boebinger et al., 2015; Madsen et al., 2019; Yeend et al., 2017). The reasons for such discrepancies across studies were attributed to methodological differences and different inclusion criteria used for musicians across studies.

Thus, aging and musical training may have opposite effects on SPiN tasks. It is crucial to prevent, reduce, or delay age-related processing impairments due to their high prevalence and negative impact on older adults. Due to its beneficial effects, we hypothesize that musical training may slow down age-related deterioration in SPiN abilities. Carnatic music incorporates microtonal distinctions not found in Western classical music (Krishnaswamy, 2004). This fundamental microtonal focus in Indian music can help integrate temporal, pitch, and intensity variations across different frequency channels, thereby improving binaural and temporal resolution (Mishra et al., 2015). The current study assesses SPiN abilities across a continuum of ages to examine the impact of aging in musicians and non-musicians. The principal focus was to determine how age affects SPiN abilities of musicians and non-musicians. The second focus was on assessing the effect of musical training on the performance of musicians and non-musicians on the SPiN test within each age range. Therefore, SPiN tests were

administered in both groups at three different SNRs and across a range of ages.

2 Methods

A cross-sectional descriptive study with a mixed design was implemented. Participants were chosen using a convenient sampling method. Initially, the subjects were advised of the study's objectives and goals, and they were asked to sign an informed consent form if they consented to participate. The study followed the All India Institute of Speech and Hearing's ethical guidelines for bio-behavioral research involving human subjects (Venkatesan and Basavaraj, 2009).

2.1 Participants

The study had 150 participants (N=150) split into five age groups: 10-19 years, 20-29 years, 30-39 years, 40-49 years, and 50-59 years. Each age group comprised 15 musicians and 15 non-musicians. Thus, 75 musicians and 75 non-musicians were assessed in five age categories. As some earlier studies have indicated that SPiN reaches adult-like scores in the second decade of life, the age range below 10 years was not considered (Yathiraj and Vanaja, 2015; Nittrouer and Boothroyd, 1990; Crandell and Smaldino, 2000; Mamatha and Yathiraj, 2019).

All participants in the older age group (50-59) passed the Mini-Mental State Examination (MMSE) (Folstein et al., 1975), and passed on the Screening Checklist for Auditory Processing in Adults (SCAP-A) (Vaidyanath and Yathiraj, 2014). The musicians were vocalists trained in Carnatic classical music for a minimum of five years. The musicians had a minimum formal music learning experience of 5 years for the younger age group (10-19) and 10 years for other age groups. It was ensured that all of them were currently practicing musicians. Instrumental musicians were not included in the study.

2.2 Test Environment

All assessments were conducted in a quiet environment with adequate lighting and ventilation. Testing was not performed in a sound-treated room, as it was logistically difficult to bring the musicians to the laboratory. However, noise levels in the test rooms were measured using a sound level meter (SLM) and remained within 50 dB(A). Furthermore, all testing was carried out with supra-aural headphones with good ambient noise attenuation.

2.3 Hearing Screening

Before commencing the audiological evaluation, a brief case history was taken. Subsequently, tests like MMSE and SCAP-A were administered in the older age group. Basic audiological tests like pure tone audiometry, immittance, and otoacoustic emission (OAE) tests were carried out. It was ensured that all participants had hearing thresholds within 15 dB HL at all audiometric frequencies, 'A' type tympanogram, present acoustic reflexes at normal sensation levels, and passed the transient otoacoustic emission screening test.

The SPiN test was performed with Sennheiser HD-569 headphones. The stimulus was delivered through headphones at 70 dB SPL [calibrated using SLM (Larsen and Davis Sound Advisor Model-831c-Type 1 SLM with AEC201 ear simulator with a frequency range up to 16000 Hz was used)] using a laptop (HP intel i3 processor, 64 GB RAM).

2.4 Procedure

SPiN was tested using recorded sentences from the Kannada sentence identification test (Geetha et al., 2014). This test has 25 homogeneous lists with 10 sentences in each list. Six lists were randomly selected from the 25 homogeneous lists. The stimulus was presented at 70 dB SPL binaurally. The subjects were evaluated at +5, 0, and -5 dB signal-to-noise ratio (SNR) levels. The four-talker babble used in this experiment was generated in-house, following the method used in previous studies (Jagadeesh and Uppunda, 2019, 2021a, 2021b). It was created by combining reading samples from four neurotypical, native Kannada-speaking adult females. To obtain signal-to-noise ratios (SNRs) of 5, 0, and -5 dB, the sentences and babble were mixed using a custom MATLAB script (Gnanateja, 2017). The desired SNR was achieved by adjusting the babble amplitude while maintaining a constant speech amplitude. The sentences were mixed with random portions of the babble, which started 500 ms before and continued 500 ms after the target sentence. Two lists were presented per SNR. The test procedure was explained to the participants. The participants were informed that noise-embedded words or sentences would be audible through the headphones. The subjects repeated the words as they heard them, even if they had to guess the words from context or only listened to a few words or sections of the speech. There were four keywords in each sentence. When the word was repeated correctly, a score of one was given; incorrect or partially accurate repetitions received a score of zero. The total scores for both lists at each SNR were averaged for each subject and converted to percent correct speech identification scores (% correct SIS).

2.5 Statistical Analysis

The data was analyzed using the Statistical Package for Social Sciences (SPSS, 20.0) software. The data distribution was analyzed using the Shapiro-Wilk's normality test. Since the data followed a normal distribution, a two-way repeated measures ANOVA was conducted to analyze the main and interaction effects among the

three independent variables: SNRs, age groups, and musicianship (where SNR was the independent variable with three levels within). In instances of sphericity violation as per Mauchly's sphericity test, Greenhouse-Geisser corrections were used. The percentage of variance, sometimes referred to as partial eta squared (η_p^2) is reported as effect size (Gravetter and Wallnau, 2013). The partial eta squared shows the amount of influence that the independent variable(s) had on the dependent variable. The effect sizes were classified as per Cohen's (1988). To further explore the interactions, one-way repeated measures ANOVA was performed separately for musicians and non-musicians. Post-hoc analysis with Bonferroni corrections for multiple comparisons was done using Independent t-tests to examine the effects of age for each SNR. The effect of musicianship in each age group for all three SNRs was assessed using independent t-tests.

3 Results

Independent t-tests revealed no significant differences between the pure tone threshold and otoacoustic emission amplitudes between musicians and non-musicians ($p > 0.05$). The results of independent t-tests for threshold and OAEs are shown in Tables 1 and 2. Figures 1 (a) and 1 (b) show the Mean and SD values for mean pure tone thresholds for the Right and Left ear, respectively, for musicians and non-musicians.

Figures 2, 3, and 4 show the Mean and SD of SPiN scores for musicians and non-musicians across different age groups at +5, 0, and -5 dB SNRs, respectively.

A two-way repeated Measure ANOVA (RM ANOVA) was conducted with SNRs as the within-subject factor and the musicianship and age groups as the between-subject factors. The results of the test showed that age groups [$F(4,140)=37.944$, $p < 0.001$, $\eta_p^2=0.520$], musicianship [$F(1,140)=285.744$, $p < 0.001$, $\eta_p^2=0.671$], and SNRs [$F(1.785, 249.888)=45787.715$, $p < 0.001$, $\eta_p^2=0.997$] all had a significant main effect. Also, age groups and musicianship had a significant interaction effect [$F(4,140)=2.442$,

Table 1 Results of Independent t-tests on 4 frequency Pure-Tone Average in Non-Musicians and Musicians in Right and Left ears across different age groups.

Groups	Age Groups	Right Ear			Left Ear		
		t	df	p	t	df	p
Non-Musicians & Musicians	10-19 years	0.653	28	0.519	0.486	28	0.631
	20-29 years	0.165	28	0.870	0.368	28	0.715
	30-39 years	1.006	28	0.323	0.168	28	0.868
	40-49 years	0.543	28	0.592	0.431	28	0.670
	50-59 years	0.568	28	0.574	0.256	28	0.800

$p < 0.01$ (corrected alpha). If $p > 1.000$, the value is approximated to 1.000.

Table 2 Results of Independent t-tests of OAE amplitudes in Non-Musicians and Musicians in Right and Left ears across different age groups.

Groups	Age Groups	Right Ear			Left Ear		
		t	df	p	t	df	p
Non-Musicians & Musicians	10-19 years	0.426	28	0.674	0.109	28	0.914
	20-29 years	0.455	28	0.653	0.323	28	0.749
	30-39 years	0.423	28	0.676	0.072	28	0.944
	40-49 years	0.719	28	0.478	0.973	28	0.339
	50-59 years	0.363	28	0.719	0.770	28	0.448

$p < 0.01$ (corrected alpha). If $p > 1.000$, the value is approximated to 1.000.

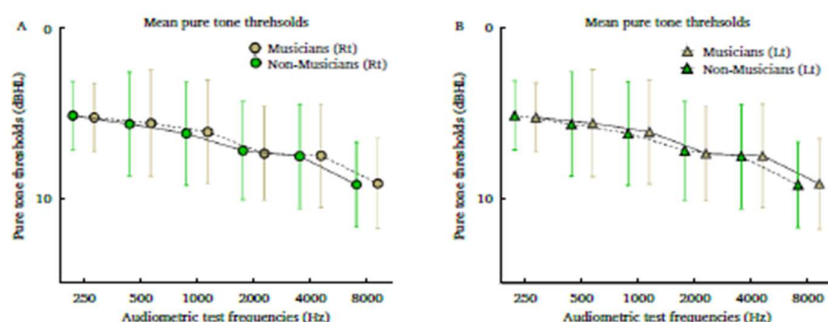


Figure 1 (a) and Figure 1 (b): Mean and one SD (error bars) of mean pure tone thresholds for Non-Musicians and Musicians for the Right and Left ears.

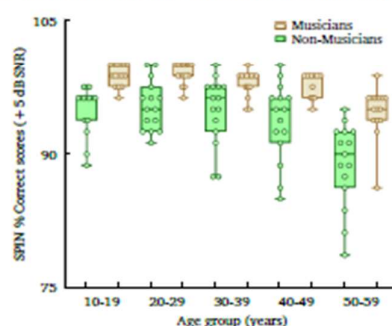


Figure 2 Mean and SD (error bars) of the SPiN test at +5 dB SNR across different age groups in Non-Musicians and Musicians. Individual data points are also shown in the figure.

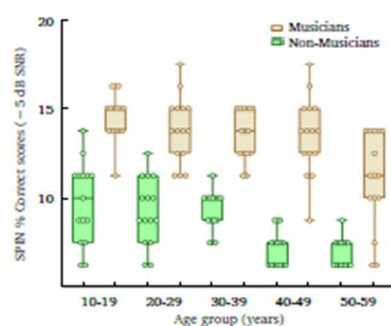


Figure 4 Mean and SD (error bars) of the SPiN test at -5 dB SNR across different age groups in Non-Musicians and Musicians. Individual data points are also shown in the figure.

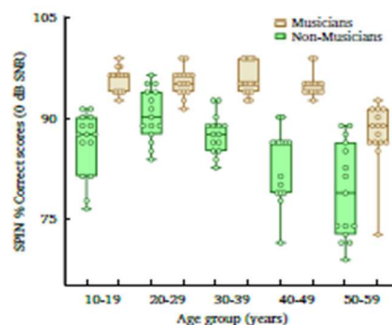


Figure 3 Mean and SD (error bars) of the SPiN test at 0 dB SNR across different age groups in Non-Musicians and Musicians. Individual data points are also shown in the figure.

$p=0.050$, $\eta^2=0.065$). Furthermore, a significant interaction was seen between SNRs and age group [$F(7.140, 249.888)=7.639$, $p<0.001$, $\eta^2=0.179$] as well as between SNRs and musicianship [$F(1.785, 249.888)=29.187$, $p<0.001$, $\eta^2=0.173$]. Age groups, musicianship, and SNR all showed significant interactions [$F(7.140, 249.888)=2.181$, $p=0.035$, $\eta^2=0.059$]. The interaction effects indicated a small to large effect size for our study ($\eta^2=0.05$ to 0.17) (Cohen, 1988). The interaction effect indicates that the pattern of SPiN performance varied for musicians and non-musi-

cians across different age groups. Interaction effects as observed in Figures 2, 3, and 4 indicate that

- deterioration of the SPiN ability with advancing age was slower in musicians compared to non-musicians
- deterioration of SPiN with advancing age was faster at poorer SNRs.

To explore these interaction effects further, follow-up one-way RM ANOVAs were carried out. One-way RM ANOVA in non-musicians, using SNRs as the within-subject factor and age groups as the between-subject factor, showed that SNRs [$F(1.786, 125.054)=15398.145$, $p=0.001$, $\eta^2=0.995$] and age groups [$F(4,70)=16.251$, $p<0.001$, $\eta^2=0.482$] had a significant main effect. There was a significant interaction effect [$F(7.146, 125.054)=4.657$, $p<0.001$, $\eta^2=0.210$] between SNRs and age groups. In musicians, One-way RM ANOVA showed a significant main effect of age [$F(4,70)=32.426$, $p<0.001$, $\eta^2=0.649$] and SNR [$F(1.709, 119.656)=43488.445$, $p<0.001$, $\eta^2=0.998$] along with an interaction effect between age groups and SNR [$F(6.837, 119.656)=5.604$, $p<0.001$, $\eta^2=0.243$]. Tables 3, 4, and 5 show the results of post-hoc analyses along with Bonferroni's corrections for multiple comparisons for +5, 0 and -5 dB SNRs. The tables show that aging differentially affected SPiN abilities across SNRs and between musicians and non-musicians. Differences between the two groups were more pronounced at 0 and -5 dB SNR. At 0 and -5 dB SNR non-musicians showed deterioration at an earlier age (40 years) compared to musicians (50 years). Also, at all age groups SPiN abilities of musicians were significantly better compared to their age-

Table 3 Results of independent t-tests in Non-Musicians and Musicians across different age groups for percent correct SPiN scores at +5 dB SNR (df = 28).

Age Groups	Non-Musicians		Musicians	
	t value	p-value	t value	p-value
10-19 & 20-29	0.415	0.681	0.384	0.704
10-19 & 30-39	0.069	0.945	1.871	0.072
10-19 & 40-49	1.004	0.324	1.999	0.055
10-19 & 50-59	4.343	<0.001***	3.186	<0.001***
20-29 & 30-39	0.412	0.684	2.229	0.034
20-29 & 40-49	1.309	0.201	2.385	0.024
20-29 & 50-59	4.611	<0.001***	3.415	<0.001***
30-39 & 40-49	0.837	0.410	0.000	1.000
30-39 & 50-59	3.849	<0.001***	0.458	<0.001***
40-49 & 50-59	2.868	0.080	3.965	<0.001***

p < 0.005 (corrected alpha). If p > 1.000, the value is approximated to 1.000. *p < 0.05, **p < 0.01, ***p < 0.001.

Table 4 Results of independent t-tests in Non-Musicians and Musicians across different age groups for percent correct scores SPiN at 0 dB SNR (df = 28).

Age Groups	Non-Musicians		Musicians	
	t value	p-value	t value	p-value
10-19 & 20-29	2.720	0.011	0.594	0.557
10-19 & 30-39	1.038	0.308	4.670	0.737
10-19 & 40-49	1.713	0.098	4.959	0.205
10-19 & 50-59	3.221	0.003***	6.246	<0.001***
20-29 & 30-39	2.265	0.031	0.211	0.834
20-29 & 40-49	4.410	<0.001***	0.594	0.557
20-29 & 50-59	3.465	<0.001***	3.795	<0.001***
30-39 & 40-49	2.986	0.006	0.791	0.436
30-39 & 50-59	4.345	<0.001***	3.836	<0.001***
40-49 & 50-59	1.737	0.093	3.609	<0.001***

p < 0.005 (corrected alpha). If p > 1.000, the value is approximated to 1.000. *p < 0.05, **p < 0.01, ***p < 0.001.

matched non-musician counterparts at all SNRs. The results of the independent t-test are shown in Table 6.

4 Discussion

According to the current study, musicians of all ages had a clear advantage in SPiN tasks compared to non-musicians. Thus, musicians may therefore be less vulnerable to the degenerative effects of aging on SPiN.

Results of the present investigation demonstrated no distinction in the aging trend between musicians and non-musicians at +5 dB SNR. However, at 0 and -5 dB SNRs, the non-musicians showed age effects in terms of deterioration of scores starting at the 40-49 age itself. However, age effects were exhibited by musicians only in the 50-59 age group at 0 and -5 dB SNRs as shown in Tables 4 and 5.

Parbery-Clark et al. (2009a) conducted electrophysiological research on young adults. The results of speech-evoked ABR with noise showed that musicians had a greater amplitude and early response, suggesting that musicians show an advantage on SPiN measurements. Learning music has been shown to generate plastic changes and strengthen subcortical and cortical processing pathways involved in speech perception. Research by Gaser and

Table 5 Results of independent t-tests in Non-Musicians and Musicians across different age groups for percent correct SPiN scores at -5 dB SNR (df = 28).

Age Groups	Non-Musicians		Musicians	
	t value	p-value	t value	p-value
10-19 & 20-29	0.656	0.517	1.278	0.212
10-19 & 30-39	0.761	0.453	2.016	0.053
10-19 & 40-49	4.026	<0.001***	1.653	0.110
10-19 & 50-59	4.249	<0.001***	4.652	<0.001***
20-29 & 30-39	0.000	1.000	0.415	0.681
20-29 & 40-49	3.794	<0.001***	0.451	0.655
20-29 & 50-59	4.427	<0.001***	3.364	0.002***
30-39 & 40-49	3.330	<0.001***	0.125	0.902
30-39 & 50-59	6.497	<0.001***	3.305	0.003***
40-49 & 50-59	0.757	0.455	2.804	0.009

p < 0.005 (corrected alpha). If p > 1.000, the value is approximated to 1.000. *p < 0.05, **p < 0.01, ***p < 0.001.

Schlaug (2003) revealed that the gray matter (cortex) volume was lowest in non-musicians, moderate in novice musicians, and

Table 6 Results of Independent t-tests comparing Non-Musicians and Musicians within each age group on SPiN tasks ($d' = 28$).

Groups	Age Groups	SNR +5		SNR 0		SNR -5	
		t	p	t	p	t	p
Non-Musicians & Musicians	10-19 years	5.002	< 0.001	7.271	< 0.001	7.132	< 0.001
	20-29 years	4.595	< 0.001	4.251	< 0.001	6.719	< 0.001
	30-39 years	2.856	0.008	8.281	< 0.001	9.276	< 0.001
	40-49 years	3.610	< 0.001	8.240	< 0.001	10.248	< 0.001
	50-59 years	4.130	< 0.001	3.868	< 0.001	5.653	< 0.001

p < 0.01 (corrected alpha). *p < 0.05, **p < 0.01, ***p < 0.001.

highest in skilled musicians (at least one hour of practice each day). Furthermore, the study's conclusions indicated that motor regions, anterior superior parietal areas, and inferior temporal areas were among the brain regions implicated in music perception. In our study, we observed a slower onset of aging in musicians compared to non-musicians, which may be attributed to the anatomical and physiological changes that are documented earlier as a result of musical training.

Speech and music share the brain's sensory or cognitive processing pathways and functions, according to the expanded OPERA theory (Patel, 2014). Musical training can improve speech processing since it puts a more significant strain on these systems than speech does. According to Patel (2014), this theory demonstrates how learning music causes adaptive changes in the speech-processing networks of the brain. In the systematic review and meta-analysis done by Maillard et al. (2023) in adults, the study comprised 38 out of 49 articles, most of which focused on young adults. A positive relationship between music and SPiN ability was evident, with minimum to no effect at better SNRs and the most outstanding advantages observed at poorer SNRs. Musicianship had a moderate effect on SPiN at SNR < 0 dB and 0 dB SNR conditions but no benefit at SNRs > 0 dB. These results align with the descriptive analysis made by Coffey et al. (2017). Similarly, findings are reported by others as well (Taitelbaum-Swead and Fostick, 2016; Heidari et al., 2018). Results of the current study also align with these observations that musicianship advantage on SPiN is more pronounced at poorer SNRs.

Another important finding of the current study is that age-related deterioration in SPiN began later in musicians compared to non-musicians. The meta-analysis of Maillard et al. (2023) also indicated a definitive advantage of music training in older adults on SPiN results compared with younger adults. The current results along with the literature provide evidence that musical training may delay age-related decline in sensory processing.

5 Conclusions

Music training can significantly delay or lessen the degenerative consequences of the aging process on SPiN. Furthermore, the current study found that music training increases SPiN capacities in people of different age groups. Thus, musical activities, if incorporated into a comprehensive rehabilitation strategy, may promote healthy aging.

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Conflicts of interest

The authors have no competing interests to declare that are relevant to the content of this article.

Code availability

Not applicable

Authors' contributions

Both authors were involved in the study design, data analysis, interpretation, and manuscript writing. KS was involved in data collection and stimulus preparation.

Ethics approval

The AIISH ethical committee approved the study method for bio-behavioral research.

Consent to participate

Written informed consent was obtained before commencing data collection.

Consent for publication

Informed content was obtained from subjects participating in the study.

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Research Article

Effect of Age on Psychoacoustic Abilities in Musicians and Nonmusicians

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Abstract

Background: Studies on psychoacoustic tests have demonstrated that musicians have superior perceptual abilities compared with nonmusicians in a specific, narrow age range. Whether this advantage is consistent across different age ranges is unclear. The extent to which these benefits will offset the detrimental effects of aging is unexplored.

Purpose: There is a strong need to study whether music training can help reduce the impact of degenerative aging effects on perceptual tasks. Hence we investigated how music training impacts psychoacoustic abilities across a continuum of age groups.

Research Design: A cross-sectional descriptive mixed design was used for the study since both between- and within-group designs were employed.

Study Sample: The study included 150 subjects, 75 musicians and 75 nonmusicians, in a continuum of age range. There were 15 musicians and 15 nonmusicians in each age group (10–19.11, 20–29.11, 30–39.11, 40–49.11, and 50–59.11 years). Musicians were trained in Carnatic classical music for at least 5 years.

Data Collection and Analysis: MATLAB software was used to administer the maximum likelihood procedure-based psychoacoustic tests. Thresholds were established for the pitch discrimination test (PDT), duration discrimination test (DDT), and gap detection test (GDT). The response criterion was the threshold corresponding to the psychometric function's 79.4 percentage point.

Results: All three measures followed a Gaussian distribution ($p > 0.05$). Results of two-way analysis of variance indicated a significant musicianship effect on all three auditory perceptual tests ($p < 0.001$). A significant age effect was noted in PDT and GDT ($p < 0.001$). Interaction effects were present on all tests ($p < 0.01$). The main effects of musicianship, age, and their interaction showed a "high" effect size on PDT, whereas for DDT and GDT, their effect sizes were "low to high". Post hoc analysis indicated that age effects were evident only in nonmusicians on PDT and DDT. GDT showed an earlier age effect in nonmusicians than in musicians.

Conclusions: Music training can significantly minimize the negative impacts of aging. Continued musical training improves auditory perceptual abilities to counteract the effects of aging and perhaps aids in better speech perception.

Key Words: music training, age, psychoacoustics, pitch discrimination, duration discrimination, gap detection

Abbreviations: ANOVA = analysis of variance; daPa = decapascals; dBHL = decibels hearing level; dB SPL = decibels sound pressure level; DDT = duration discrimination test; GDT = gap detection test; MEMR = middle ear muscle reflex; MLP = maximum likelihood procedure; ms = milliseconds; OAE = otoacoustic emission; PDT = pitch discrimination test; PTA = pure tone average; SD = standard deviation; SLM = sound level meter; TEOAE = transient evoked otoacoustic emission

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Conflict of Interest: None declared.

INTRODUCTION

Aging causes changes in the anatomic and physiological components of an otherwise typically functioning auditory system (Howarth and Shone, 2006). The peripheral and central systems must function effectively for the auditory system to operate adequately. Aging brings about a decline in the performance of perceptual and cognitive tasks, although the hearing sensitivity may be well preserved at standard audiometric frequencies (Houtgast and Festen, 2008). In a constantly aging population, finding lifestyles/skills that effectively attenuate age-related perceptual, cognitive decline and brain atrophy is indispensable. One such skill is music learning.

Music is "the art or science of arranging sounds in notes and rhythms to produce a pleasing pattern or effect" (Cross and Morley, 2010). Continued exposure to formal music training alters the auditory system's structure, behavior, and functionality, improving numerous auditory abilities. Professional musicians have higher "active auditory association areas" than nonmusicians (Gaab and Schlaug, 2003). Thus, understanding musicians' performance on tests that assess temporal processing and auditory discrimination abilities across different age groups will be worthwhile.

A former study revealed that a higher difference limen by a ratio of 1.8 at 500 Hz and 2.3 at 1000 Hz was reported in older adults compared with young adults (Abel et al, 1990). Older adults have demonstrated poorer performance and greater variability in duration discrimination than younger individuals (Bergeson et al, 2001). An earlier study reported an age-related decline in gap-detecting thresholds (Palmer and Musiek, 2014).

Musicians, however, have demonstrated superior auditory attention skills and better outcomes than nonmusicians on psychoacoustic tests (Bidelman et al, 2011; Nisha et al, 2022). But only two studies from the past reported no difference in perception tasks; one used pitch discrimination and gap detection task (Fujisaki and Kashino, 2002), and the other used gap detection task alone (Alexandre et al, 2010). This was attributed to methodological differences and a smaller sample size. However, a former systematic review revealed that musicians performed significantly better than nonmusicians on pitch discrimination and gap detection (Braz et al, 2021). These studies focused either on a narrow age group or considered only around 30 participants. Lifelong instrumental musicians aged 18 to 91 showed a delayed age effect on gap detection tasks compared with nonmusicians, confirming musicianship advantage (Zendel and Alain, 2012).

Although music training helps with auditory cues, people become less proficient in using binaural (Strouse et al, 1998) and spectral cues as they age (Dobrev et al, 2011). Thus, aging and musical training have opposite effects on the performance of psychoacoustic tasks. Due

to its high prevalence and harmful consequences, it is crucial to prevent, mitigate, or delay "age-related processing deficits." Carnatic music is densely filled with microtonal variations not found in Western classical music (Krishnaswamy, 2004). This inherent quality of Indian music's microtonal emphasis can aid in precisely processing temporal, pitch, and intensity changes in sounds across frequency channels, resulting in improvements in binaural and temporal resolution (Mishra et al, 2014). No studies, to date, have considered a continuum of age ranges to systematically study the effects of aging in musicians and nonmusicians on perceptual tasks.

The current research aimed to compare the psychoacoustic abilities across a continuum of ages in musicians and nonmusicians. The objective was to study the effect of age and music training on perceptual tasks in musicians and nonmusicians. Hence tests like the pitch discrimination test (PDT), duration discrimination test (DDT), and gap detection test (GDT) were administered because they determine the spectral and temporal processing abilities that are crucial for speech perception.

METHOD

A cross-sectional descriptive study approach with a mixed design was used. The participants were chosen using a convenient sampling technique. Before the study began, each participant was informed of its aims and objectives and advised to sign the informed consent form on their approval. Musicians were chosen from different music schools and concerts if they satisfied the inclusion criteria and consented to participate in the study. The study followed the "ethical guidelines for bio-behavioral research involving human subjects" of the "All India Institute of Speech and Hearing" (Venkatesan and Basavaraj, 2009).

Participants

The study included 150 subjects ($N = 150$) divided into five age groups: 10–19.11, 20–29.11, 30–39.11, 40–49.11, and 50–59.11 years. Each age group had 15 musicians and 15 nonmusicians. Thus, 75 musicians and 75 nonmusicians from five different age groups were tested. Pitch and duration discrimination and gap detection abilities become adultlike at around 8.5 years (Dincer D'Alessandro et al, 2015), by 8–10 years (Elfenbein et al, 1993) and 6–7 years (Shivaprakash and Manjula, 2003), respectively. Hence the proposed age ranges were chosen.

The number of years of Carnatic classical vocal music experience that the participants had was 5–10, 8–18, 10–25, 20–30, and 10–50 years in the 10–19.11, 20–29.11, 30–39.11, 40–49.11, and 50–59.11 years age groups, respectively. Thus, a minimum of 5 (for 10–19.11 age

group) to 10 years (other age groups) of music experience was considered. The instrumental musicians were not included. The musicians were primarily instructed one-on-one or in a small homogenous group consisting of a maximum of four to five people in such groups.

Test Environment

All audiological examinations were conducted in a quiet setting with enough lighting and ventilation. A "quiet setting" was selected to ensure low background noise levels and that the tested sounds were easily heard and accurately measured.

Hearing Screening

Before commencing the audiological evaluation, a brief case history was taken. Subsequently, older participants (50–59.11 age group) underwent screening for cognitive abilities with the Mini-Mental State Examination (Folstein et al, 1975), and those who scored more than 24 were included in the study. Older adults who scored more than 50 percent on the Screening Checklist for Auditory Processing—Adults were excluded from the study (Vaidyanath and Yathiraj, 2014).

Basic audiological tests such as pure tone audiometry, immittance, and otoacoustic emission (OAE) were carried out. The "absolute threshold" test was administered to determine hearing thresholds using the maximum likelihood procedure (MLP) (Soranzo and Grassi, 2014) through MATLAB (version R, 2014a) software installed in an HP laptop. Sennheiser HD-569 headphones provided the stimulus for threshold estimation and all psychoacoustic tests. Pure tones from 250 Hz to 8 kHz of 500 milliseconds duration (ms) with 10 ms cosine squared envelopes were presented binaurally for threshold estimation. Thirty stimuli were presented binaurally, and thresholds were tracked using the "yes-no" method, wherein the subject was asked to report if the sound was heard. The threshold was the mean between the level not heard and the level last heard by the participant. The thresholds were compared with the absolute threshold values of MLP obtained on 30 individuals (age = 20–30 years) with hearing thresholds within 15 dBHL (decibels hearing level) at all audiometric frequencies. They were not a part of the study participant sample and were selected through convenience sampling.

A calibrated immittance instrument (Path Medical Sentiero) was used for acoustic reflex testing and tympanometry. Tympanometry was tested by varying pressure from –200 decapascals (daPa) to +200 daPa at a rate of 200 daPa/second while using a probe tone frequency of 226 Hz at 85 dB SPL. Subjects had "A" or "As" type tympanogram and present reflexes. Middle ear muscle reflexes (MEMRs) were elicited at 500 and 1000 Hz for all

participants in both groups across all age groups. A screening OAE instrument, Maico Ero Scan, was employed to record transient evoked otoacoustic emissions (TEOAEs). TEOAEs were evoked by clicks at 85 decibels peak sound pressure level. All participants obtained TEOAEs at signal-to-noise ratios greater than 6 dB, fulfilling the pass criteria.

Procedure

Psychoacoustic tests were administered using the MLP in the MATLAB software. Each test consisted of one block of 30 trials. Each trial had three sound intervals, and the participant had to identify the sound interval with a variable acoustic feature. The stimulus was delivered through headphones at 70 decibels sound pressure level (dB SPL) (calibrated using sound level meter (SLM; Larsen and Davis Sound Advisor Model-831c-Type 1 SLM with AEC201 ear simulator with a frequency response up to 16,000 Hz) with the laptop volume set to deliver 70 dB SPL. Three-interval alternate forced-choice procedures were used to track a 79.4 percentage point on the psychometric curve.

For PDT and DDT tests, the reference frequency was a 250-ms 1000-Hz tone with 10-ms raised cosine ramps at onset and offset (Soranzo and Grassi, 2014). The participant had to identify the stimulus with the higher frequency. The minimum and maximum steps of the variant stimulus were 0.1 and 100 Hz. The smallest frequency difference corresponding to the psychometric function's 79.4 percentage point was determined using MLP. In MLP, the psychometric function that gives the maximum likelihood to arrive at the response is presented as the subsequent stimulus, maximizing the possibility of reaching the threshold with fewer trials.

The block with a longer duration had to be identified for the DDT test; the minimum and maximum duration deviations were 0.1 and 200.1 ms, respectively. The calculated value was the duration difference corresponding to the psychometric function's 79.4 percentage point using MLP (Soranzo and Grassi, 2014). The GDT test had a 750-ms Gaussian noise with 0.5-ms cosine ramps at the start and end. The minimum and maximum gaps were 0.1 and 64 ms. The subject had to identify the stimulus interval with the variable noise containing a gap within. The calculated value was the gap detection threshold corresponding to the psychometric function's 79.4 percentage point using MLP (Soranzo and Grassi, 2014). Figures 1–3 show the graphical representation of PDT, DDT, and GDT test stimuli, respectively, demonstrating the baseline and variable sound intervals.

Statistical Analysis

The data were statistically analyzed using IBM Corp's Statistical Package for Social Sciences (SPSS) software version 20.0. Shapiro-Wilk test was used to analyze the

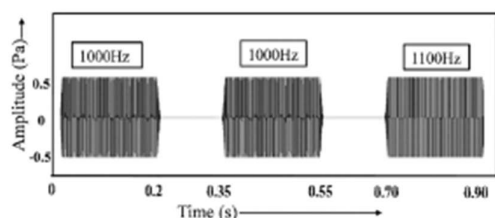


Figure 1. Graphical representation of pitch discrimination test stimulus with three sound intervals (two low- and one high-frequency stimulus) requiring the participant to identify the tone with a higher pitch.

data's probability distribution. Parametric tests were used for Gaussian data, and nonparametric tests were used for non-Gaussian data.

RESULTS

Supplemental Figures S1–S3 show the mean and one standard deviation (SD) of four-frequency pure tone average (PTA), global TEOAEs, and ipsilateral MEMR thresholds (at 500 and 1000 Hz), respectively, across five different age groups in the musician and non-musician groups. Independent *t* tests showed no significant differences between the PTA values ($p > 0.05$), OAE amplitudes ($p > 0.05$), and MEMR thresholds ($p > 0.05$) between the two groups at all age groups. MEMR results showed an exception at 500 Hz in the right ear in the 50–59.11 years age group, where musicians had a significantly poorer threshold. Details of the test statistic and significance levels are provided in Supplemental Tables S1–S4. Figures 4–6 show the mean and one SD values of PDT, DDT, and GDT thresholds for both groups across different ages. Shapiro-Wilk test showed Gaussian distribution for all of the measures ($p > 0.05$). Hence parametric tests were used.

PDT

Two-way analysis of variance (ANOVA) with musicianship and age groups as the between-subject factors

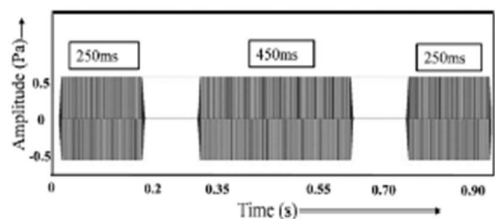


Figure 2. Graphical representation of duration discrimination test stimulus with three sound intervals (two short and one long stimulus) requiring the participant to identify the tone with a longer duration.

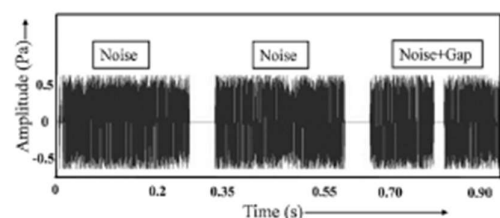


Figure 3. Graphical representation of gap detection test stimulus with three sound intervals (two noise intervals and one with a gap in the noise) requiring the participant to identify the gap interval in the stimulus.

indicated significant main effects of musicianship [$F(1,140) = 197.599$, $p < 0.001$, $\eta^2 = 0.585$] and age [$F(4,140) = 6.300$, $p < 0.001$, $\eta^2 = 0.153$] and a significant interaction effect [$F(4,140) = 6.839$, $p < 0.001$, $\eta^2 = 0.163$]. The degree of the association between two variables in a population or sample is measured by “effect size.” The partial η^2 is one of the measures used to determine the effect size, which represents the degree of influence the independent variable(s) has on the dependent variable (Cohen, 2013). PDT scores in our study were significantly impacted (with a “high” effect size) by musicianship ($\eta^2 = 0.585$), age ($\eta^2 = 0.153$), and their interaction ($\eta^2 = 0.163$). Independent *t* tests with Bonferroni's correction for multiple comparisons showed that musicians had significantly better PDT than nonmusicians in all of the age groups ($p < 0.001$). The results of the independent *t* tests are given in Table 1. Furthermore, one-way ANOVA showed a significant age effect in nonmusicians [$F(4,70) = 6.773$, $p < 0.001$, $\eta^2 = 0.279$], but not in musicians [$F(4,70) = 0.741$, $p = 0.567$, $\eta^2 = 0.041$]. Follow-up independent *t* tests with Bonferroni's corrections for multiple comparisons showed that PDT deteriorated in nonmusicians

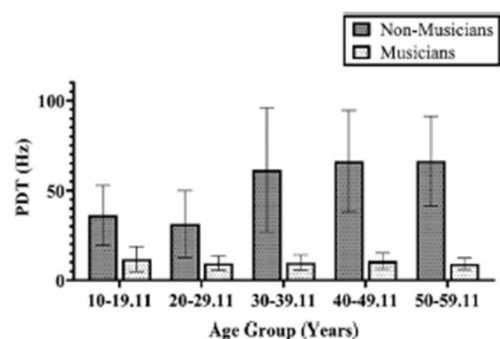


Figure 4. Mean and standard deviation (error bars) for thresholds on the pitch discrimination test across different age groups in musicians and nonmusicians. PDT = pitch discrimination threshold in the figure.

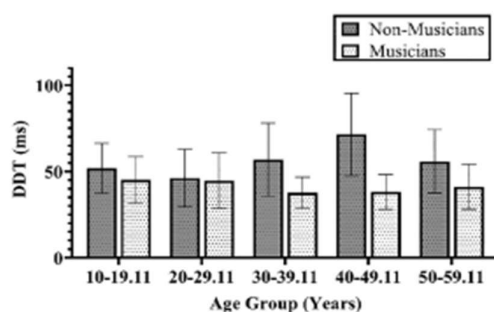


Figure 5. Mean and standard deviation (error bars) for thresholds on the duration discrimination test across different age groups in musicians and nonmusicians. DDT = duration discrimination threshold in the figure.

from 30–39.11 years onward. However, musicians did not show age effects. The results are given in Table 2.

DDT

Two-way ANOVA indicated that there was a significant main effect of musicianship [$F(1,140) = 32.348$, $p < 0.001$, $\eta^2 = 0.188$] and interaction effect [$F(4,140) = 4.326$, $p = 0.002$, $\eta^2 = 0.110$] with no significant main effect of age [$F(4,140) = 1.443$, $p = 0.223$, $\eta^2 = 0.040$]. Thus, musicianship had a “high” effect size ($\eta^2 = 0.188$), the interaction had a “medium” effect size ($\eta^2 = 0.11$), and the age effect had a “low” effect size ($\eta^2 = 0.040$). Independent t tests with Bonferroni’s correction showed that nonmusicians performed at par with musicians until 20–29.11 years. From 30 to 39.11 years of age, musicians performed better than nonmusicians. The results are given in Table 1. One-way ANOVA was done to resolve the effect of interaction between age groups and musicianship. The test results revealed a significant main

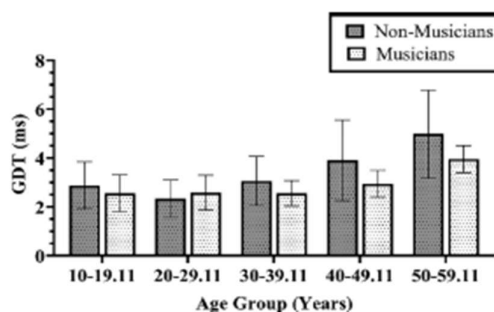


Figure 6. Mean and standard deviation (error bars) for thresholds on the gap detection test across different age groups in musicians and nonmusicians. GDT = gap detection threshold in the figure.

effect of age groups in the nonmusician group [$F(4,70) = 3.627$, $p = 0.010$, $\eta^2 = 0.172$], but not in the musician group [$F(4,70) = 1.161$, $p = 0.335$, $\eta^2 = 0.062$]. Age effects in nonmusicians were analyzed using independent t tests with Bonferroni’s corrections. Aging showed degrading effects on DDT at 40–49.11 years in the nonmusician group. Age effects were absent in musicians. The results of independent t tests are given in Table 3.

GDT

Two-way ANOVA demonstrated significant main effects of musicianship [$F(1,140) = 13.773$, $p < 0.001$, $\eta^2 = 0.090$] and age [$F(4,140) = 22.499$, $p < 0.001$, $\eta^2 = 0.391$] and a significant interaction effect [$F(4,140) = 3.805$, $p < 0.01$, $\eta^2 = 0.098$]. Musicianship and interaction had a “medium” effect size ($\eta^2 = 0.090$ and $\eta^2 = 0.098$), and age effect had a “high” effect size ($\eta^2 = 0.391$). Independent t tests with Bonferroni’s corrections indicated that musicians performed comparably with nonmusicians until 30–39.11 years. From 40–49.11 years of age, musicians performed better than nonmusicians. The results of the independent t tests are given in Table 1. One-way ANOVA was conducted to analyze the interaction effect between musicianship and age effects. Results revealed a significant age effect both in nonmusicians [$F(4,70) = 13.057$, $p < 0.001$, $\eta^2 = 0.427$], and in musicians [$F(4,70) = 13.683$, $p < 0.001$, $\eta^2 = 0.439$]. Independent t tests with Bonferroni’s corrections indicated performance deterioration in nonmusicians and musicians at 40–49.11 and 50–59.11 years, respectively. The results are given in Tables 4 and 5.

DISCUSSION

Two significant findings of this study are: (1) the musician group outperformed the nonmusician group on all three psychoacoustic tests, especially at older ages, and (2) age-related decline in performance was observed only in the nonmusician group. On the PDT, the musician group demonstrated better pitch discrimination abilities than the nonmusician group. On temporal processing tests, such as the DDT and the GDT, both groups performed similarly in younger age groups. However, age-related deterioration was evident in the older nonmusician group. In contrast, older adults in the musician group performed on par with their younger counterparts. These findings suggest that musical training and continued practice slow the age-related decline in basic psychoacoustic abilities.

Physiologically, aging is associated with reduced neurons in auditory nuclei and reduced neuronal synchronization (Goossens et al., 2016), reduced precision of temporal coding at neural and central levels (Bergeson et al., 2001; Grassi et al., 2017), delayed adaptation recovery, and deterioration in neuronal inhibition because of reduced

Table 1. Results of Independent t Tests Comparing Musicians and Nonmusicians Within Each Age Group

Groups	Age Groups (Years)	PDT			DDT			GDT		
		t	df	Corrected p	t	df	p	t	df	Corrected p
Musicians and nonmusicians	10–19.11	5.197	28	<0.005**	1.295	28	0.206	1.037	28	0.309
	20–29.11	4.406	28	<0.005**	0.253	28	0.802	0.904	28	0.374
	30–39.11	5.725	28	<0.005**	3.325	28	0.003**	1.692	28	0.102
	40–49.11	7.522	28	<0.005**	5.004	28	<0.005**	2.122	28	<0.05*
	50–59.11	8.807	28	<0.005**	2.524	28	<0.05*	3.020	28	<0.005**

DDT = duration discrimination test; df = degrees of freedom; GDT = gap detection test; PDT = pitch discrimination test.
 *p < 0.05, **p < 0.01, ***p < 0.001. Corrected p-value = (actual p-value) * number of pairwise comparisons.

inhibitory neurotransmitters (Alain et al, 2004; Goossens et al, 2016). These physiological changes can result in reduced perceptual abilities on these tasks. Music training, however, induces structural changes in the brain, leading to increased gray matter volume in motor, visuospatial, and auditory regions (Gaser and Schlaug, 2003), corpus callosum, and a larger superior temporal gyrus and posterior cingulate gyrus compared with nonmusicians (Groussard et al, 2014). Functional magnetic resonance imaging studies done earlier have indicated improved functional connectivity in the motor and multi-sensory cortices in musicians after music training (Luo et al, 2012). Musicians evidence better auditory discrimination and temporal processing abilities because of better phase-locking; improved subcortical, neural, and synaptic plasticity; and precise neural response timing (Zendel and Alain, 2012; Strait and Kraus, 2014). The effects of music training in improving perceptual abilities like pitch discrimination (Bidelman et al, 2011; Braz et al, 2021), duration discrimination (Grassi et al, 2017), and gap detection abilities (Mishra et al, 2014; Nisha et al, 2022) have been reported in earlier studies, which concurs with our findings.

In addition, another significant finding was that age-linked deterioration was more evident in nonmusicians compared with musicians. Similar findings have been reported earlier on gap-detection abilities in nonmusicians

compared with lifelong musicians (Zendel and Alain, 2012). Continued musical training may improve cognitive reserve, freeing perceptual, attentional, and cognitive resources that might be used to analyze auditory inputs (Zendel and Alain, 2012). Improved cognitive reserve may benefit older individuals on perceptual tasks who have structural and functional insufficiencies and cannot process auditory inputs at par with younger individuals as a result of aging. Maintaining musical practice can also lead to increased neural capacity, neural efficiency, or the capacity to compensate by recruiting more brain regions during auditory processing (Zendel and Alain, 2012). Thus, learning music improves one's ability to absorb auditory information by causing neuroplastic changes in the auditory cortex and subcortex or through enhanced cognitive strategies. Earlier studies in younger and older musicians and nonmusicians have indicated a greater deterioration in older nonmusicians on perceptual tasks than older musicians, which is similar to our study's findings (Zendel and Alain, 2012; Grassi et al, 2017; Nisha et al, 2022). Based on all these outcomes, it can be said that musical training slows down the effect of aging on perceptual tasks.

Our study results suggest that "musical training" might have a protective/beneficial effect and that it does become evident in the range of 30–40 years age bracket when it is expected for the general population to start showing signs

Table 2. Results of Independent t Tests in Nonmusicians Across Different Age Groups on PDT

Age Groups (years)	t Value	df	Corrected p Value
10–19.11 and 20–29.11	0.742	28	1.000
10–19.11 and 30–39.11	2.540	28	0.085
10–19.11 and 40–49.11	3.542	28	0.005**
10–19.11 and 50–59.11	3.894	28	0.005**
20–29.11 and 30–39.11	2.956	28	0.03*
20–29.11 and 40–49.11	3.983	28	<0.01**
20–29.11 and 50–59.11	4.439	28	<0.01**
30–39.11 and 40–49.11	0.420	28	1.000
30–39.11 and 50–59.11	0.458	28	1.000
40–49.11 and 50–59.11	0.021	28	1.000

p significance level: *p < 0.05, **p < 0.01, ***p < 0.001. Corrected p-value = (actual p-value) * number of pairwise comparisons.
 df = degrees of freedom.

Table 3. Results of Independent t Tests in Nonmusicians Across Different Age Groups on DDT

Age Groups (years)	t Value	df	Corrected p Value
10–19.11 and 20–29.11	0.987	28	1.000
10–19.11 and 30–39.11	0.764	28	1.000
10–19.11 and 40–49.11	2.739	28	0.055*
10–19.11 and 50–59.11	0.658	28	1.000
20–29.11 and 30–39.11	1.539	28	1.000
20–29.11 and 40–49.11	3.378	28	0.010**
20–29.11 and 50–59.11	1.503	28	1.000
30–39.11 and 40–49.11	1.787	28	0.425
30–39.11 and 50–59.11	0.150	28	1.000
40–49.11 and 50–59.11	2.033	28	0.26

p significance level: *p < 0.05. Corrected p-value = (actual p-value) * number of pairwise comparisons.
 df = degrees of freedom.

Table 4. Results of Independent t Tests in Nonmusicians Across Different Age Groups on GDT

Age Groups (years)	t Value	df	Corrected p Value
10–19.11 and 20–29.11	1.700	28	0.500
10–19.11 and 30–39.11	0.475	28	1.000
10–19.11 and 40–49.11	2.076	28	0.235
10–19.11 and 50–59.11	4.475	28	<0.01**
20–29.11 and 30–39.11	2.183	28	0.19
20–29.11 and 40–49.11	3.332	28	0.010*
20–29.11 and 50–59.11	5.421	28	<0.01**
30–39.11 and 40–49.11	1.712	28	0.49
30–39.11 and 50–59.11	4.197	28	<0.01**
40–49.11 and 50–59.11	2.620	28	0.07

p significance level: *p < 0.05, **p < 0.001. Corrected p-value = (actual p-value) * number of pairwise comparisons.
df = degrees of freedom.

of age-related hearing loss/perceptual loss. Frequency discrimination and temporal resolution are the fundamental aspects of speech perception (Glasberg and Moore, 1989). With music training, musicians identify tiny sound contrasts in duration and pitch as music has more frequency and amplitude variations than speech (Chasin, 2003).

Summary and Conclusions

Musicians are consistently better than nonmusicians at psychoacoustic tasks because they constantly train to detect such features in acoustic signals. This training is shown to potentially tune the auditory system (anatomically and physiologically) to efficiently and accurately process sound environments (Chasin, 2003), and these capabilities could even be transferred to speech perception (Besson et al, 2011). Thus, music training enables better temporal resolution and active auditory discrimination abilities, particularly in older adults, which may enable better speech comprehension (Glasberg and Moore, 1989; Besson et al, 2011). These subjective outcomes must be correlated with objective test findings in a continuum

Table 5. Results of Independent t Tests in Musicians Across Different Age Groups on GDT

Age Groups (years)	t Value	df	Corrected p Value
10–19.11 and 20–29.11	0.116	28	1.000
10–19.11 and 30–39.11	0.020	28	1.000
10–19.11 and 40–49.11	1.635	28	1.000
10–19.11 and 50–59.11	5.769	28	<0.01**
20–29.11 and 30–39.11	0.116	28	1.000
20–29.11 and 40–49.11	1.568	28	1.000
20–29.11 and 50–59.11	5.870	28	<0.01**
30–39.11 and 40–49.11	1.983	28	0.285
30–39.11 and 50–59.11	7.069	28	<0.01**
40–49.11 and 50–59.11	4.918	28	<0.01**

p significance level: ***p < 0.001. Corrected p-value = (actual p-value) * number of pairwise comparisons.
df = degrees of freedom.

of age groups to encourage music learning and materialize music-based rehabilitation.

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