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Nonmusicians Experience Early Aging on Working Memory Tasks Compared to Musicians

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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 (ηp2 = 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 dBSPL 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 dBSPL.

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.

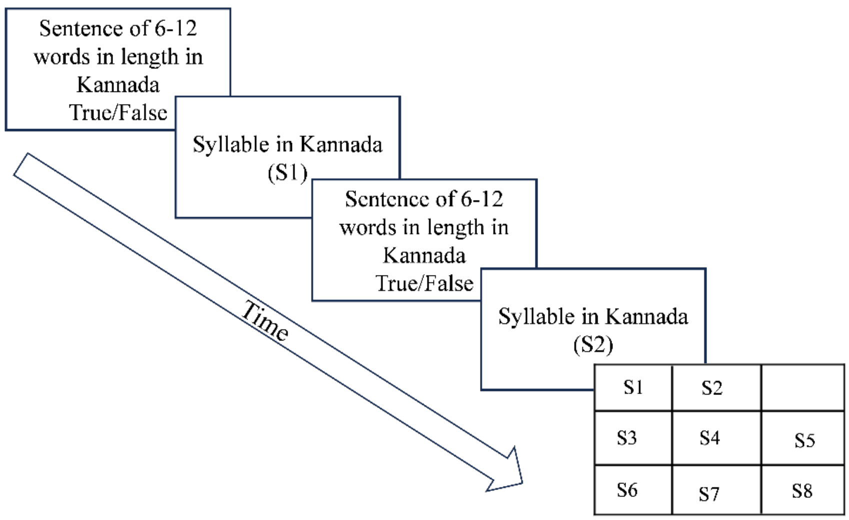
The absolute threshold test was used for threshold estimation using the MLP approach. Pure tones with 10 ms cosine-squared envelopes and frequencies ranging from 250 Hz to 8 kHz were presented binaurally. The psychometric function that gives the maximum likelihood of getting the response is displayed 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 dBHL 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 dBSPL 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 dBSPL. 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., Naukaranige varʃad̪alli eradu ba:ri ma:t̪ra katʃɛ:rige ho:galu anumat̪i ni:ɖala:gut̪t̪ad̪e 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.*

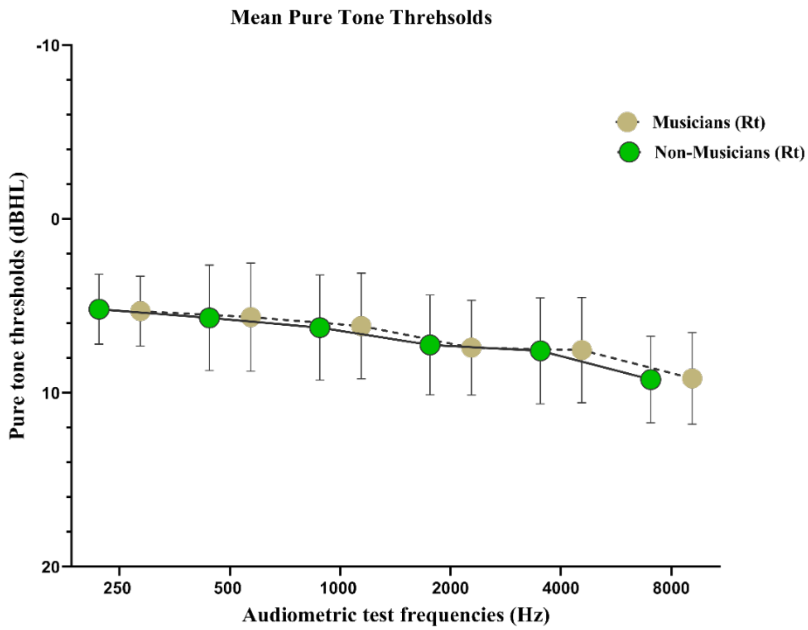
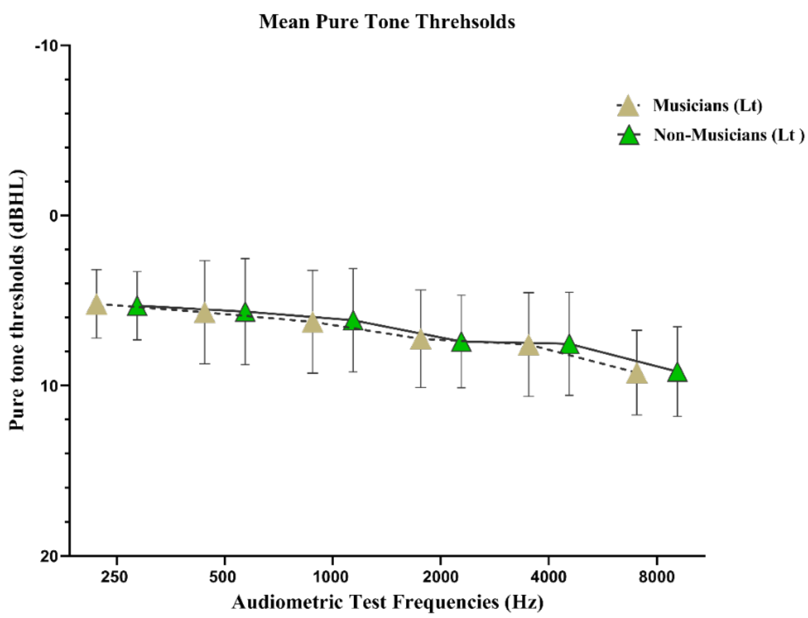


Figure 3. *Mean and One SD (Error Bars) of Pure Tone Thresholds for Musicians and Nonmusicians for the Left Ear.*



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.*

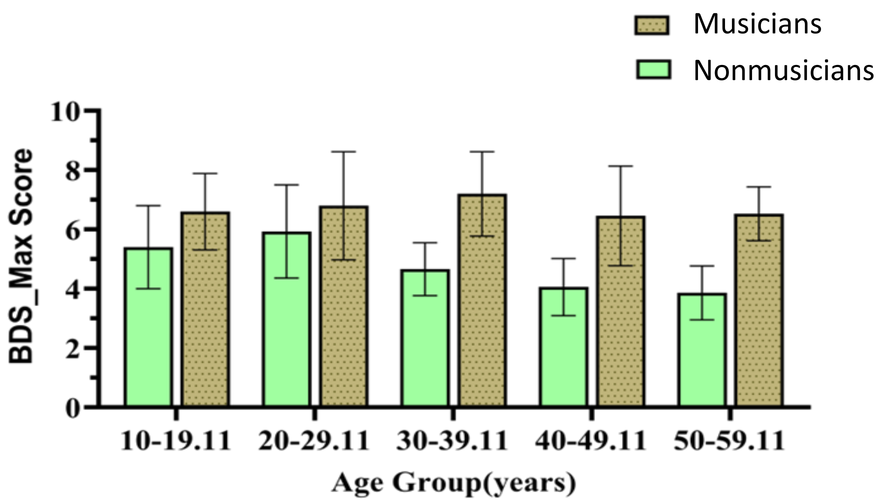
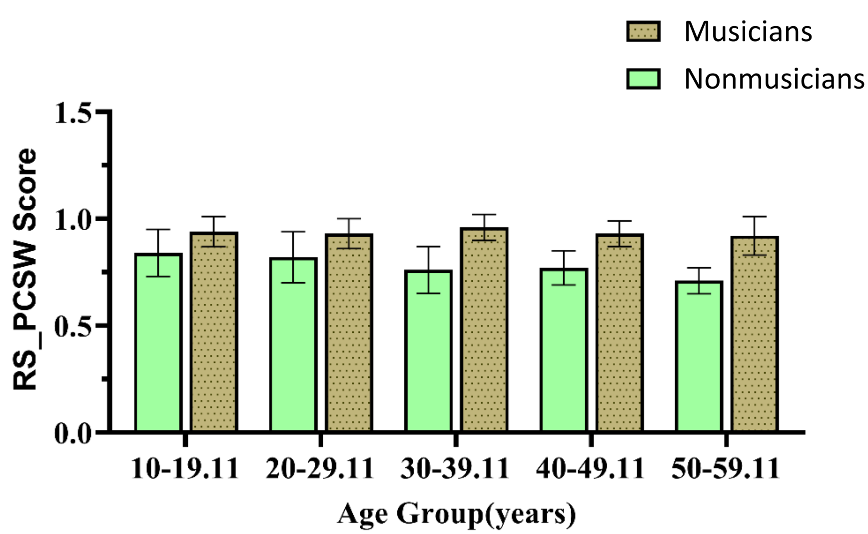


Figure 5. *Mean and SD (Error Bars) for RS PCSW Scores Across Different Age Groups in Musicians and Nonmusicians.*



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, $F(1, 140) = 78.999$, $p = .001$, $\eta p2 = 0.361$; there was a significant age effect, $F(4, 140) = 4.280$, $p = .003$, $\eta p2 = 0.109$; and an interaction effect between musicianship and age effects, $F(4, 140) = 2.950$, $p = .022$, $\eta p2 = 0.078$. 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, $F(4, 70) = 8.179$, $p = .001$, $\eta p2 = 0.319$. However, there was no significant age effect in musicians, $F(4, 70) = 0.613$, $p = .654$, $\eta p2 = 0.034$. 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, $F(1, 140) = 116.760$, $p = .001$, ηp2 = 0.455, and an age effect, $F(4, 140) = 3.382$, $p = .011$, ηp2 = 0.088 were found; however, a significant interaction effect was not seen, $F(4, 140) = 2.320$, $p = .060$, ηp2 = 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, $F(4, 70) = 4.006$, $p = .006$, ηp2 = 0.186, whereas the same was not present in the musician group, $F(4, 70) = 0.705$, $p = .591$, ηp2 = 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 (ηp2). 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 (ηp2 = 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 (Münte 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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References

Barrett, K. C., Ashley, R., Strait, D. L., & Kraus, N. (2013). Art and science: How musical training shapes the brain. *Frontiers in Psychology*, *4*, Article 713. https://doi.org/10.3389/fpsyg.2013.00713

Bergman Nutley, S., Darki, F., & Klingberg, T. (2014). Music practice is associated with development of working memory during childhood and adolescence. *Frontiers in Human Neuroscience, 7*, Article 926. https://doi.org/10.3389/fnhum.2013.00926

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

Bregman, A. S. (1990). *Auditory scene analysis: The perceptual organization of sound*. The MIT Press.

Chan, A. S., Ho, Y.-C., & Cheung, M.-C. (1998). Music training improves verbal memory. *Nature, 396*(6707), Article 128. https://doi.org/10.1038/24075

Cohen, J. (2013). *Statistical power analysis for the behavioral sciences*. Routledge. https://doi.org/10.4324/9780203771587

Conway, A. R. A., Kane, M. J., Bunting, M. F., Hambrick, D. Z., Wilhelm, O., & Engle, R. W. (2005). Working memory span tasks: A methodological review and user's guide. *Psychonomic Bulletin & Review, 12*(5), 769–786. https://doi.org/10.3758/bf03196772

Folstein, M. F., Folstein, S. E., & McHugh, P. R. (1975). "Mini-mental state": A practical method for grading the cognitive state of patients for the clinician. *Journal of Psychiatric Research, 12*(3), 189–198. https://doi.org/10.1016/0022-3956(75)90026-6

Franklin, M. S., Sledge Moore, K., Yip, C. Y., Jonides, J., Rattray, K., & Moher, J. (2008). The effects of musical training on verbal memory. *Psychology of Music, 36*(3), 353–365. https://doi.org/10.1177/0305735607086044

Gaab, N., & Schlaug, G. (2003). The effect of musicianship on pitch memory in performance matched groups. *NeuroReport, 14*(18), 2291–2295. https://doi.org/10.1097/00001756-200312190-00001

George, E. M., & Coch, D. (2011). Music training and working memory: An ERP study. *Neuropsychologia, 49*(5), 1083–1094. https://doi.org/10.1016/j.neuropsychologia.2011.02.001

Gignac, G. E. (2015). The magical numbers 7 and 4 are resistant to the Flynn effect: No evidence for increases in forward or backward recall across 85 years of data. *Intelligence, 48*, 85–95. https://doi.org/10.1016/j.intell.2014.11.001

Gignac, G. E., & Weiss, L. G. (2015). Digit Span is (mostly) related linearly to general intelligence: Every extra bit of span counts. *Psychological Assessment, 27*(4), 1312–1323. https://doi.org/10.1037/pas0000105

Guo, X., Ohsawa, C., Suzuki, A., & Sekiyama, K. (2018). Improved digit span in children after a 6-week intervention of playing a musical instrument: An exploratory randomized controlled trial. *Frontiers in Psychology, 8*, Article 2303. https://doi.org/10.3389/fpsyg.2017.02303

Grassi, M., & Soranzo, A. (2009). MLP: A MATLAB toolbox for rapid and reliable auditory threshold estimation. *Behavior Research Methods, 41*(1), 20–28. https://doi.org/10.3758/BRM.41.1.20

Hansen, M., Wallentin, M., & Vuust, P. (2013). Working memory and musical competence of musicians and non-musicians. *Psychology of Music, 41*(6), 779–793. https://doi.org/10.1177/0305735612452186

Helmbold, N., Rammsayer, T., & Altenmüller, E. (2005). Differences in primary mental abilities between musicians and nonmusicians. *Journal of Individual Differences, 26*(2), 74–85. https://doi.org/10.1027/1614-0001.26.2.74

Houtgast, T., & Festen, J. M. (2008). On the auditory and cognitive functions that may explain an individual's elevation of the speech reception threshold in noise. *International Journal of Audiology, 47*(6), 287–295. https://doi.org/10.1080/14992020802127109

Howarth, A., & Shone, G. R. (2006). Ageing and the auditory system. *Postgraduate Medical Journal, 82*(965), 166–171. https://doi.org/10.1136/pgmj.2005.039388

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

Krishnaswamy, A. (2004). Inflexions and microtonality in South Indian classical music. *Frontiers of Research on Speech and Music*.

Kumar, A. U., & Sandeep, M. (2013). *Auditory cognitive training module*. ARF funded departmental project submitted to All India Institute of Speech and Hearing, Mysore.

Lee, Y.-S., Lu, M.-J., & Ko, H.-P. (2007). Effects of skill training on working memory capacity. *Learning and Instruction, 17*(3), 336–344. https://doi.org/10.1016/j.learninstruc.2007.02.010

Maillard, E., Joyal, M., Murray, M. M., & Tremblay, P. (2023). Are musical activities associated with enhanced speech perception in noise in adults? A systematic review and meta-analysis. *Current Research in Neurobiology, 4*, Article 100083. https://doi.org/10.1016/j.crneur.2023.100083

Martin, M., Zöllig, J., & Jäncke, L. (2009). The plastic human brain. *Restorative Neurology and Neuroscience, 27*(5), 521–538. https://doi.org/10.3233/RNN-2009-0519

Matysiak, O., Kroemeke, A., & Brzezicka, A. (2019). Working memory capacity as a predictor of cognitive training efficacy in the elderly population. *Frontiers in Aging Neuroscience, 11*, Article 126. https://doi.org/10.3389/fnagi.2019.00126

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

Muñoz-Pradas, R., Díaz-Palacios, M., Rodriguez-Martínez, E. I., & Gómez, C. M. (2021). Order of maturation of the components of the working memory from childhood to emerging adulthood. *Current Research in Behavioral Sciences, 2*, Article 100062. https://doi.org/10.1016/j.crbeha.2021.100062

Münte, T. F., Altenmüller, E., & Jäncke, L. (2002). The musician's brain as a model of neuroplasticity. *Nature Reviews Neuroscience, 3*(6), 473–478. https://doi.org/10.1038/nrn843

Owen, A. M., McMillan, K. M., Laird, A. R., & Bullmore, E. (2005). N-back working memory paradigm: A meta-analysis of normative functional neuroimaging studies. *Human Brain Mapping, 25*(1), 46–59. https://doi.org/10.1002/hbm.20131

Pais, R., Ruano, L., P Carvalho, O., & Barros, H. (2020). Global cognitive impairment prevalence and incidence in community dwelling older adults—A systematic review. *Geriatrics (Basel, Switzerland), 5*(4), Article 84. https://doi.org/10.3390/geriatrics5040084

Reynolds, M. R., Niileksela, C. R., Gignac, G. E., & Sevillano, C. N. (2022). Working memory capacity development through childhood: A longitudinal analysis. *Developmental Psychology, 58*(7), 1254–1263. https://doi.org/10.1037/dev0001360

Richardson, J. T. E. (2011). Eta squared and partial eta squared as measures of effect size in educational research. *Educational Research Review, 6*(2), 135–147. https://doi.org/10.1016/j.edurev.2010.12.001

Román-Caballero, R., Arnedo, M., Triviño, M., & Lupiáñez, J. (2018). Musical practice as an enhancer of cognitive function in healthy aging - A systematic review and meta-analysis. *PLoS ONE, 13*(11), Article e0207957. https://doi.org/10.1371/journal.pone.0207957

Saarikivi, K. A., Huotilainen, M., Tervaniemi, M., & Putkinen, V. (2019). Selectively enhanced development of working memory in musically trained children and adolescents. *Frontiers in Integrative Neuroscience, 13*, Article 62. https://doi.org/10.3389/fnint.2019.00062

Sanchez, C. A., Wiley, J., Miura, T. K., Colflesh, G. J. H., Ricks, T. R., Jensen, M. S., & Conway, A. R. A. (2010). Assessing working memory capacity in a non-native language. *Learning and Individual Differences, 20*(5), 488–493. https://doi.org/10.1016/j.lindif.2010.04.001

Schellenberg, E. G. (2006). Long-term positive associations between music lessons and IQ. *Journal of Educational Psychology, 98*(2), 457–468. https://doi.org/10.1037/0022-0663.98.2.457

Schlaug, G., Jäncke, L., Huang, Y., & Steinmetz, H. (1995). In vivo evidence of structural brain asymmetry in musicians. *Science (New York, N.Y.), 267*(5198), 699–701. https://doi.org/10.1126/science.7839149

Sluzenski, J., Newcombe, N. S., & Kovacs, S. L. (2006). Binding, relational memory, and recall of naturalistic events: A developmental perspective. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 32*(1), 89–100. https://doi.org/10.1037/0278-7393.32.1.89

Talamini, F., Altoè, G., Carretti, B., & Grassi, M. (2017). Musicians have better memory than nonmusicians: A meta-analysis. *PLoS ONE, 12*(10), Article e0186773. https://doi.org/10.1371/journal.pone.0186773

Talamini, F., Carretti, B., & Grassi, M. (2016). The working memory of musicians and nonmusicians. *Music Perception: An Interdisciplinary Journal, 34*(2), 183–191. https://doi.org/10.1525/MP.2016.34.2.183

Tervaniemi, M., Just, V., Koelsch, S., Widmann, A., & Schröger, E. (2005). Pitch discrimination accuracy in musicians vs nonmusicians: An event-related potential and behavioral study. *Experimental Brain Research, 161*(1), 1–10. https://doi.org/10.1007/s00221-004-2044-5

Vaidyanath, R., & Yathiraj, A. (2014). Screening checklist for auditory processing in adults (SCAP-A): Development and preliminary findings. *Journal of Hearing Science, 4*(1), 27–37. https://doi.org/10.17430/890788

Venkatesan, S., & Basavaraj, V. (2009). *Ethical guidelines for bio-behavioral research involving human subjects, 1–23*. Mysore, India: All India Institute of Speech & Hearing. https://www.aiishmysore.in/en/pdf/ethical_guidelines.pdf

Vuontela, V., Steenari, M.-R., Carlson, S., Koivisto, J., Fjällberg, M., & Aronen, E. T. (2003). Audiospatial and visuospatial working memory in 6-13 year old school children. *Learning & Memory (Cold Spring Harbor, N.Y.), 10*(1), 74–81. https://doi.org/10.1101/lm.53503

Yathiraj, A., & Vanaja, C. S. (2015). Age related changes in auditory processes in children aged 6 to 10 years. *International Journal of Pediatric Otorhinolaryngology, 79*(8), 1224–1234. https://doi.org/10.1016/j.ijporl.2015.05.018

Zuk, J., Benjamin, C., Kenyon, A., & Gaab, N. (2014). Behavioral and neural correlates of executive functioning in musicians and nonmusicians. *PLoS ONE, 9*(6), Article e99868. https://doi.org/10.1371/journal.pone.0099868

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