https://ruralneuropractice.com

ScientificScholar® Knowledge is power
Publisher of Scientific Journals

Journal of Neurosciences in Rural Practice

Original Article

Music and the aging brain – Exploring the role of long-term Carnatic music training on cognition and gray matter volumes

Aishwarya Ghosh[1], Sadhana Singh[1], Monisha S.[1], Tejaswini Jagtap[1], Thomas Gregor Issac[1]

[1]Centre for Brain Research, Indian Institute of Science, Bengaluru, Karnataka, India.

ABSTRACT

Objectives: Aging is a natural process and is often associated with an increased incidence of cognitive impairment. Physical exercise, diet, and leisure activities (music, dance, and art) are some of the lifestyle factors that contribute to healthy aging. The present study aims to explore the differences in cognitive functioning between aging individuals involved in musical activity throughout their lifetime and the ones who were not.

Materials and Methods: Fifty-one healthy elderly individuals (50–80 years of age) residing in an urban locality were selected for the study from the Tata Longitudinal Study of Aging cohort. Participants were divided into two groups: Active musicians trained in Carnatic music for more than five years (n = 18) and age-matched non-musicians (n = 33). Addenbrooke cognitive examination-III, Hindi mental status examination, and trail-making test-B (TMT-B) were used to assess cognitive functioning. A Generalized Linear Regression Model was performed including covariates such as gender, age, and years of education. We also looked at the available brain magnetic resonance imaging data of a subset of our study population to inspect the volumetric differences between musicians and non-musicians.

Results: Our results showed that musicians had significantly better visuospatial abilities as compared to non-musicians (P = 0.043). Musicians (130.89 ± 45.16 s) also took less time to complete the TMT-B task than non-musicians (148.73 ± 39.65 s), although it was not a statistically significant difference (P =0.150). In addition, brain imaging data suggested that musicians had increased gray matter volumes in the right precuneus, right post-central gyrus, right medial and superior frontal gyrus, right orbital gyrus, left middle temporal gyrus, left cuneus, left fusiform gyrus, and bilateral cingulate gyrus.

Conclusion: Our findings are indicative of music being an important attribute in improving cognitive reserve and predicting cognitive resilience. These findings pave the way to explore the utility of non-pharmacological interventions, such as Music Therapy (especially Carnatic music in the Indian context), as a potential factor for improving cognitive reserve in elderly individuals.

Keywords: Music, Cognitive functioning, Elderly, Visuospatial, Gray matter, Gray matter volume

INTRODUCTION

The link between aging and cognitive functioning has always been intriguing. Aging is a natural process that brings about changes in the trajectories of cognitive functioning as well as brain volumes.[1] Functional decline of cognition in the domains of processing speed, attention, working memory, visuospatial abilities, and executive functions along with a decrease in total brain volume and atrophy of cortical gray matter (GM), and temporal and frontal lobes are part of normal aging.[2] Certain lifestyle and environmental factors such as involvement in musical activities often contribute to the cognitive reserve, which helps in counteracting age-related decline in cognition to a certain extent.[3] Often, a discrepancy is noticed between a person's level of age-related cognitive decline as explained by brain pathology and observed functioning – this can also be explained by the concept of cognitive reserve.[4] Besides education, engagement in socially and cognitively stimulating activities such as physical exercise, musical, and leisure activities throughout one's lifetime contribute to cognitive reserve, thereby reducing the risk of dementia.[5,6]

Music has been claimed to have positive associations with cognitive functioning and high-functioning individuals are often exposed to musical training at an early age.[7] Playing an instrument (drums and piano) and/or singing is associated with multilevel sensorimotor processing, which requires higher cognitive processes such as attention, working memory, visual memory, and executive functioning, which collectively contribute to cognitive reserve and improved functioning.[8-11] Hanna-Pladdy and Gajewski's study reported that recent involvement in musical activities was associated with better visuospatial

***Corresponding author:** Thomas Gregor Issac, Centre for Brain Research, Indian Institute of Science, Bengaluru, Karnataka, India. thomasgregor@iisc.ac.in

Received: 28 November 2023 **Accepted:** 14 March 2024 **Epub ahead of print:** 12 April 2024 **Published:** 07 May 2024 **DOI:** 10.25259/JNRP_605_2023

abilities, while early life acquisition of music was related to better auditory-verbal memory in aging individuals – suggesting a protective role of music against age-related cognitive decline.[12]

The functional advantages of musical training or practice are accompanied by structural changes in the brain that have been observed in neuroimaging studies. Gaser and Schlaug found that there was a significant increase in GM volumes among musicians (keyboard players) as compared to non-musicians in the brain areas involved in auditory, motor, and visuospatial functioning.[13] Musicians have been found to have increased GM density in brain areas, which include the right fusiform gyrus, right mid-orbital gyrus, left inferior frontal gyrus, left intraparietal sulcus, and left Heschl's gyrus – these areas are involved in higher-order cognitive functioning.[14]

These insights led us to explore the differences in cognitive functioning between musicians and their non-musician counterparts after matching for age, gender, and education. Moreover, our investigation extends to scrutinizing structural changes in musical brains versus age-matched non-musical brains. Our hypothesis posits that musicians would likely exhibit superior cognitive functioning and higher GM volumes as compared to non-musicians.

MATERIALS AND METHODS

Study population

Participants (n = 51) with substantial interest in music aged between 50 and 80 years were identified from the cohort of the Tata Longitudinal Study for Aging (TLSA). Subsequently, a telephonic interview was conducted to gather further details from them. We defined *musicians* as participants, who were involved in musical activities (Carnatic music vocalists) for not <5 years in their lifetime and *non-musicians* as participants with <5 years or no involvement in the same.[15] These individuals were then divided into musicians (n = 18) and non-musicians (n = 33). The TLSA study protocol is approved by the Institutional Ethics Committee and followed all ethical guidelines ensuring participants' safety, confidentiality, and voluntary participation.

For structural MR-based evaluation, we have taken a subset (n = 33) of participants whose data was available, and it consisted of 13 musicians and 20 non-musicians.

All the participants were bilingual, English speaking, without a history of psychiatric, neurologic, cardiovascular illnesses, head injury (e.g., concussions and trauma), and current alcohol or substance abuse and had clinical dementia rating (Hughes, Berg, Danziger, Coben, and Martin, 1982) score of zero indicative of normal cognitive functioning.[16] Participants with claustrophobia, non-magnetic resonance imaging (MRI) compatible implants (dental implants, pacemakers, etc.), severe developmental delay, inability to actively participate in the study or self-report were excluded from the study.

Cognitive assessments

The cognitive functioning of the participants was assessed using the following:

Addenbrooke's cognitive examination-III (ACE-III)

It is a cognitive screening tool available in different languages consisting of tests for attention, orientation, memory, language, visuoperceptual, and visuospatial abilities.[17]

Hindi mental status examination (HMSE)

It is the Hindi version of the mini-mental status examination, which is a globally used cognitive screening tool. The HMSE consists of timed subtests to assess global cognitive functioning.[18]

Trail-making test-B (TMT-B)

The TMT-B is a freely available, time-bound neuropsychological test used to assess executive functioning. It consists of numbers and letters, which are to be connected alternatively in an ascending order. It is scored by tracking the time taken to complete the test and if an individual is unable to complete it within five min, the test is discontinued.[19]

MRI

A 3 Tesla MRI system (Magnetom Prisma, Siemens) was used for conducting all the brain imaging studies. Participants were made to lie in a supine position with their heads placed between two foam pads on both sides to reduce head movement. To obtain high-resolution T1-weighted images, the Magnetization-Prepared Rapid Acquisition Gradient Echo sequence with specific imaging parameters (Repetition time = 2300 ms, echo time = 2.26 ms, inversion time = 900 ms, field of view = 256 × 240 mm^2, matrix size = 256 × 256, slice thickness = 1 mm, number of slices = 176) was used in sagittal plane.

Data processing

The Statistical Parametric Mapping Package SPM12 (Wellcome Department of Cognitive Neurology, UK; http://www.fil.ion.ucl.ac.uk/spm/) and custom MATLAB-based software (The MathWorks Inc., Natick, MA) were used for image processing. A detailed description of the structural data processing steps is provided. MRI images' registration was enhanced by Diffeomorphic Anatomic Registration through the Exponentiated Lie Algebra (DARTEL) algorithm toolkit. The first step involved segmentation of the GM and WM probability maps, clicking the "new segment" option of SPM12. Next, the generation of flow fields and template image series was done using the "DARTEL (create templates)" option. Finally, the flow fields and template images were used to smoothen (10-mm full width at half maximum), modulate, and spatially normalize the anatomical images into the montreal neurological institute (MNI) space.

Statistical analysis

The Statistical Package for the Social Sciences Version: 28.0.1.1(15) was used for all statistical analysis. Demographic characteristics were assessed by independent samples *t*-test. To check the association in the gender frequencies between musicians and non-musicians, we used a chi-square of significance. In addition, a Generalized Linear Regression Model was used to see the changes in cognitive scores between the two groups, using age, gender, and education as covariates. Statistical significance was considered at $P < 0.05$.

Analysis of covariance was performed to compare the smoothed whole-brain GM maps of musicians and non-musicians and regional GM volume differences between groups were obtained. Age, gender, and education were taken as covariates. A whole-brain analysis was performed considering a significance level of $P < 0.001$, uncorrected for multiple comparisons.

RESULTS

Demographic characteristics

Demographic data of musicians and non-musicians is summarized in Table 1. No significant differences in age ($P = 0.997$), gender ($P = 0.525$), and education ($P = 0.756$) appeared between groups.

Neurocognitive findings

Details of the neurocognitive measures of musicians and non-musicians are summarized in Table 2. Independent samples *t*-test before adjusting for age, gender, and education showed no significant difference ($P > 0.05$) between the two groups.

After adjusting for age, gender, and education, musicians showed significantly higher scores in the ACE-III visuospatial domain as compared to non-musician participants ($P = 0.043$) [Table 3].

Table 1: Mean (SDs), *P* value, and degrees of freedom (df) of demographic data of participants.

Demographic features	Musicians (*n*=18)	Non-musicians (*n*=33)	*P*-value	df
Age (in years)	60.90 (8.58)	60.89 (7.18)	0.997	49
Education (in years)	15.94 (2.28)	16.27 (4.12)	0.756	49
Gender (Percentage)				
Male	6 (33.3)	14 (42.4)	0.525	1
Female	12 (66.7)	19 (57.6)		

SDs: Standard deviations

Furthermore, musicians (130.89 ± 45.16 s) took less time than non-musicians (148.73 ± 39.65 s) to complete the TMT-B task, although it was not statistically significant.

MRI findings

Voxel-based morphometric analysis showed significantly higher GM volumes in the right precuneus, right post-central gyrus, right medial and superior frontal gyrus, right orbital gyrus, left middle temporal gyrus, left cuneus, left fusiform gyrus, and bilateral cingulate gyrus in musicians as compared to non-musicians [Figure 1].

DISCUSSION

This study aimed to investigate the cognitive aspects of musical brains (brains of trained musicians) as compared to those of non-musicians. The results of our study indicate that healthy elderly Carnatic singers have better visuospatial abilities as compared to age-matched non-musicians. In addition, we also observed an increase in GM volumes of certain brain regions in musicians as compared to non-musicians.

The benefits of music, that is, playing an instrument, singing or even listening to music have been well documented.[11] An example of this, which sparked the debate about the role of music in intelligence, was reported by Rauscher *et al.* They reported that a brief exposure (10 min) to a certain piece by Mozart had short-term improvement in spatial reasoning skills, which was called "the Mozart effect."[20] Even though the conclusions derived were controversial, it is worth exploring the beneficial effects that music has on the brain, especially on the aging brain. Long-term musical training has been attributed to theimproved encoding of auditory signals and speech perception as well as cortical plasticity through the reward circuits, especially the dopaminergic systems, thereby enhancing mood and quality of life in general.[21,22] The results of our current study show musical training to extend its benefits to visuospatial skills. Our findings are in tune with a recent study by Böttcher *et al.* where musicians were found to have better visuospatial abilities among other cognitive abilities such as language, working memory, and executive functioning.[23] A notable point in our study is that the musicians were all Carnatic singers, and it has been evidenced that Carnatic music improves spatial reasoning by activating several limbic pathways that function through cortical networks.[24] Anaya *et al.*, have also suggested that musicians are able to learn and reproduce visuospatial information better than non-musicians.[8] Earlier studies have reported musicians to have enhanced skills of motor, visuomotor, and auditory-motor functioning, which leads them to have a better understanding of visual musical symbols, auditory signals, motor commands, and temporal patterns.[25,26]

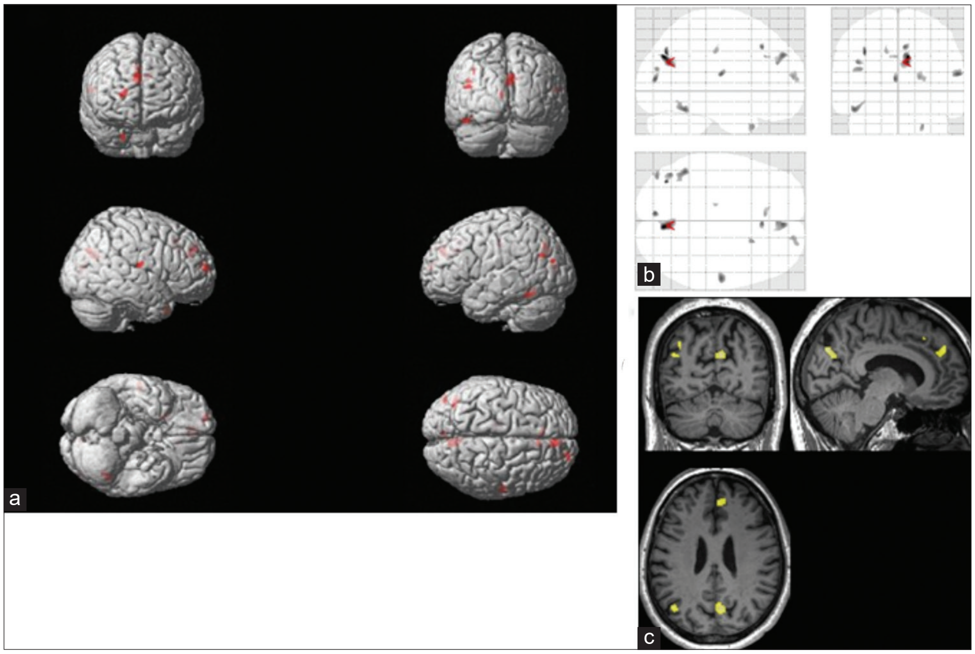

Figure 1: (a) Three-dimensional rendered view; (b) Glass-brain view provided in SPM12; and (c) overlay of the peak cluster on the background image of regions of gray matter volume loss in non-musicians as compared to musicians in voxel-based morphometric analysis.

Table 2: Mean (SDs), *P* value, and degrees of freedom (df) of neurocognitive measures of musicians and non-musicians.

Neurocognitive measures	Musicians	Non-musicians	*P*-value (95% CI)	df
ACE-III (Total)	94.72 (5.30)	93.09 (5.42)	0.306 (−1.537–4.799)	49
Attention	17.28 (0.95)	17.18 (1.10)	0.758 (−0.525–0.717)	49
Memory	24.28 (2.27)	24.12 (2.16)	0.809 (−1.139–1.452)	49
Fluency	12.78 (1.73)	12.03 (1.72)	0.146 (−0.269–1.764)	49
Language	24.94 (1.34)	24.94 (1.67)	0.991 (−0.920–0.930)	49
Visuospatial	15.44 (0.78)	14.82 (1.33)	0.074 (−0.064–1.317)	49
HMSE	30.50 (1.20)	30.58 (0.75)	0.783 (−0.625–0.473)	49
TMT-B (in seconds)	130.89 (45.16)	148.73 (39.65)	0.150 (−42.361–6.685)	49

ACE-III: Addenbrooke's cognitive examination-III, HMSE: Hindi mental status examination, TMT-B: Trail-making test-B, df: Degrees of freedom, SDs: Standard deviations, C.I.: Confidence interval. Significant at $P<0.05$ Independent measures *t*-test revealed no significant difference between the two groups (not adjusted for age, gender, and education)

Table 3: Generalized linear regression model.

Demographic features	Model 1 (Unadjusted) β (95% C.I.)	*P*-value	df	Model 2 (Adjusted) β (95% C.I.)	*P*-value	df
ACE-III (Total)	1.631 (−1.537–4.799)	0.306	49	1.866 (−1.078–4.810)	0.208	50
Attention	0.096 (−0.525–0.717)	0.758	49	0.136 (−0.484–0.755)	0.662	50
Memory	0.157 (−1.139–1.452)	0.809	49	0.240 (−0.940–1.419)	0.684	50
Fluency	0.747 (−0.269–1.764)	0.146	49	0.763 (−0.239–1.766)	0.132	50
Language	0.005 (−0.920–0.930)	0.991	49	0.034 (−0.902–0.970)	0.942	50
Visuospatial	0.626 (−0.064–1.317)	0.074	49	0.693 (0.023–1.363)	0.043*	50
HMSE	−0.076 (−0.625–0.473)	0.783	49	−0.009 (−0.53–0.514)	0.972	50
TMT-B (time taken)	−17.838 (−42.361–6.685)	0.150	49	−18.201 (−41.290–4.892)	0.119	50

Model 1: Not adjusted for age, gender, and years of education, Model 2: Adjusted for age, gender, and years of education. ACE-III: Addenbrooke's cognitive examination-III, HMSE: Hindi mental status examination, TMT-B: Trail-making test-B, C.I.: Confidence interval , df: Degrees of freedom, (*) indicates significant at $P<0.05$

In most older adults, there is an age-related decline in executive functioning along with other cognitive domains such as working memory and visuospatial ability. The musicians in our study took less time to complete the TMT-B task, which is indicative of better executive functioning even though it was not statistically significant.[19] A similar finding has been reported in a previous study by Seinfeld *et al.* where a four-month piano training intervention was found to improve executive functioning in the elderly.[9]

The advancements in brain imaging techniques have made it easier to understand the effects that music has on the brain. A recent study reported an increase in whole-brain GM volume in older adults as a result of musical training for six months.[27] Studies suggest the existence of hemispheric asymmetries in the brain with the left hemisphere specialized for linguistic and cognitive functions and the right hemisphere for visuospatial processing.[28] It is also known that music involves both the hemispheres and the right to be more active.[29] From our findings, we observe a connection between the conserved regions in musical brains and the role that they are known to play in visuospatial reasoning and executive functions. An important consideration that should be made in this regard is the familiarity of music. Specific areas in the cortex are found to be active when listening to music that is either familiar or the listener's favorite. Trained musicians show higher functional connectivity in the precuneus which is activated when listening to familiar music.[30] This finding is quite important with respect to our study, as we have noticed an increased GM volume in the precuneus of musicians. The precuneus is also known to be selectively connected to other parietal lobe regions and to mediate visuospatial information processing.[31]

The fusiform gyrus is a part of the occipitotemporal lobe, which is involved majorly in visual and auditory processing, thus playing an important role in visuospatial abilities.[32] Satoh *et al.* reported that the fusiform gyrus is further involved in multisensory perception of richness of sound and color.[33] These studies help us to establish a correlation between increased GM density in the fusiform gyrus and better visuospatial ability among the musicians in our study.

Music is also known to elicit strong emotional responses among listeners, which they describe as a chills-like sensation, called "Frissons." Such positive emotions are linked to certain brain regions such as the right orbitofrontal cortex and anterior cingulate gyrus, which also have connectivity to the reward pathways.[34,35] The increased GM volumes in the right orbital gyrus and bilateral cingulate gyrus among the musicians in this study can be attributed to their musical experiences, assuming that they experience frissons more often than non-musicians. Positive musical pieces are also known to activate the medial and superior frontal gyrus, the left precuneus, and the bilateral middle temporal gyrus, which is indicative of emotional music recognition.[36] The activation of frontal, temporal, and cingulate gyri is known to be responsible for emotion processing. The right parietal and middle frontal regions are known to be involved in memory retrieval.[37] It can be assumed that music activates the above-mentioned areas and constant musical practice keeps these cortical regions activated leading to an increased GM volume, thereby contributing to compensate for age-related atrophy.

The primary objective of this study was to ascertain the favorable impacts of music on cognition and brain health aiming to uncover the neural mechanisms behind these effects. Our study is perhaps the first of its kind to document the effects of lifetime involvement with Carnatic music on cognitive resilience in the elderly. We have tried looking into both neuropsychological and brain imaging correlates of the same. However, no study is without limitations. We did not investigate instrumentalists or non-Carnatic vocalists as well as younger adults, which could provide us with a better idea about synaptic pruning that contributed to plasticity and further meta-plasticity. Subsequent research is imperative to discern whether the benefits associated with engagement in musical activities are a result of correlation or causation. Future research should also include exploring the different genres of music and instruments (string instruments, percussions, and wind instruments) and the role they play in cognition and brain health.

CONCLUSION

Music is an important contributing factor to the maintenance of cognitive reserve and predicting cognitive resilience. Establishing the benefits music has on the aging brain would pave the way for including music as a component of therapy and popularize non-pharmacological interventions such as Music Therapy, Music Reminiscence Therapy, and Snoezelen therapy for the elderly, who experience cognitive decline, as it is also relatively safe without any long-term side effects. Another interesting aspect to investigate would be the musical genre preference and their effect on cognition and intelligence.

Acknowledgment

We are grateful to all the participants who took part in our study. We thank the TLSA members for their contributions to different aspects of the study. We also extend our gratitude to the director of our institution for his constant support and encouragement.

Ethical approval

The research/study approved by the Institutional Review Board at Centre for Brain Research, number CBR/42/IEC/2022-23, dated November 21, 2022.

Declaration of patient consent

The authors certify that they have obtained all appropriate patient consent.

Financial support and sponsorship

TATA Trusts.

Conflicts of interest

There are no conflicts of interest.

Use of artificial intelligence (AI)-assisted technology for manuscript preparation

The authors confirm that there was no use of artificial intelligence (AI)-assisted technology for assisting in the writing or editing of the manuscript and no images were manipulated using AI.

REFERENCES

1. Hedman AM, van Haren NE, Schnack HG, Kahn RS, Hulshoff Pol HE. Human brain changes across the life span: A review of 56 longitudinal magnetic resonance imaging studies. Hum Brain Mapp 2012;33:1987-2002.
2. Fujita S, Mori S, Onda K, Hanaoka S, Nomura Y, Nakao T, *et al*. Characterization of brain volume changes in aging individuals with normal cognition using serial magnetic resonance imaging. JAMA Netw Open 2023;6:e2318153.
3. Foubert-Samier A, Catheline G, Amieva H, Dilharreguy B, Helmer C, Allard M, *et al*. Education, occupation, leisure activities, and brain reserve: A population-based study. Neurobiol Aging 2012;33:423.e15-25.
4. Stern Y. Cognitive reserve in ageing and Alzheimer's disease. Lancet Neurol 2012;11:1006-12.
5. Livingston G, Huntley J, Sommerlad A, Ames D, Ballard C, Banerjee S, *et al*. Dementia prevention, intervention, and care: 2020 report of the Lancet Commission. Lancet 2020;396:413-46.
6. Schooler C, Mulatu MS. The reciprocal effects of leisure time activities and intellectual functioning in older people: A longitudinal analysis. Psychol Aging 2001;16:466-82.
7. Schellenberg EG. Examining the association between music lessons and intelligence. Br J Psychol 2011;102:283-302.
8. Anaya EM, Pisoni DB, Kronenberger WG. Visual-spatial sequence learning and memory in trained musicians. 2016;45:5-21.
9. Seinfeld S, Figueroa H, Ortiz-Gil J, Sanchez-Vives MV. Effects of music learning and p0iano practice on cognitive function, mood and quality of life in older adults. Front Psychol 2013;4:61506.
10. Degé F, Kerkovius K. The effects of drumming on working memory in older adults. Ann N Y Acad Sci 2018;1423:242-50.
11. Schneider CE, Hunter EG, Bardach SH. Potential cognitive benefits from playing music among cognitively intact older adults: A scoping review. J Appl Gerontol 2018;38:1763-83.
12. Hanna-Pladdy B, Gajewski B. Recent and past musical activity predicts cognitive aging variability: Direct comparison with general lifestyle activities. Front Hum Neurosci 2012;6:24508.
13. Gaser C, Schlaug G. Brain structures differ between musicians and non-musicians. J Neurosci 2003;23:9240-5.
14. James CE, Oechslin MS, Van De Ville D, Hauert CA, Descloux C, Lazeyras F. Musical training intensity yields opposite effects on grey matter density in cognitive versus sensorimotor networks. Brain Struct Funct 2014;219:353-66.
15. Criscuolo A, Bonetti L, Särkämö T, Kliuchko M, Brattico E. On the association between musical training, intelligence and executive functions in adulthood. Front Psychol 2019;10:442656.
16. Hughes CP, Berg L, Danziger WL, Coben LA, Martin RL. A New clinical scale for the staging of dementia. Br J Psychiatry 1982;140:566-72.
17. Hodges JR, Larner AJ. Addenbrooke's cognitive examinations: ACE, ACE-R, ACE-III, ACEapp, and M-ACE; 2017. p. 109-37. Available from: https://link.springer.com/chapter/10.1007/978-3-319-44775-9_6 [Last accessed on 2023 Oct 18].
18. Ganguli M, Ratcliff G, Chandra V, Sharma S, Gilby J, Pandav R, *et al*. A Hindi version of the MMSE: The development of a cognitive screening instrument for a largely illiterate rural elderly population in India. Int J Geriatr Psychiatry 1995;10:367-77.
19. Bhatia T, Shriharsh V, Adlakha S, Bisht V, Garg K, Deshpande S. The trail making test in India. Indian J Psychiatry 2007;49:113.
20. Rauscher FH, Shaw GL, Ky CN. Music and spatial task performance. Nature 1993;365:611.
21. Strait DL, Kraus N. Can you hear me now? Musical training shapes functional brain networks for selective auditory attention and hearing speech in noise. Front Psychol 2011;2:10051.
22. Herholz SC, Zatorre RJ. Musical training as a framework for brain plasticity: Behavior, function, and structure. Neuron 2012;76:486-502.
23. Böttcher A, Zarucha A, Köbe T, Gaubert M, Höppner A, Altenstein S, *et al*. Musical activity during life is associated with multi-domain cognitive and brain benefits in older adults. Front Psychol 2022;13:945709.
24. Amemane R, Gundmi A, Mohan KM. Effect of carnatic music listening training on speech in noise performance in adults. J Audiol Otol 2020;25:22-6.
25. Tierney AT, Bergeson TR, Pisoni DB. Effects of early musical experience on auditory sequence memory. Empir Musicol Rev 2008;3:178-86.
26. Zafranas N. Piano keyboard training and the spatial-temporal development of young children attending kindergarten classes in Greece. Early Child Dev Care 2004;174:199-211.
27. Marie D, Müller CA, Altenmüller E, Van De Ville D, Jünemann K, Scholz DS, *et al*. Music interventions in 132 healthy older adults enhance cerebellar grey matter and auditory working memory, despite general brain atrophy. Neuroimage Rep 2023;3:100166.
28. Corballis PM. Visuospatial processing and the right-hemisphere interpreter. Brain Cogn 2003;53:171-6.
29. Iuşcă D. Brain hemisphericity and music performance level in undergraduate music students and philharmonic musicians.

Procedia Soc Behav Sci 2014;142:59-63.
30. Tanaka S, Kirino E. Functional connectivity of the precuneus in female university students with long-term musical training. Front Hum Neurosci 2016;10:328.
31. Cavanna AE, Trimble MR. The precuneus: A review of its functional anatomy and behavioural correlates. Brain 2006;129:564-83.
32. Xu K, Liu R, Chen X, Yang Y, Wang Q. Brain structure variability study in pilots based on VBM. PLoS One 2023;18:e0276957.
33. Satoh M, Nagata K, Tomimoto H. Sound richness of music might be mediated by color perception: A PET study. Behav Neurol 2015;2015:2414804.
34. Rolls ET. The orbitofrontal cortex and emotion in health and disease, including depression. Neuropsychologia 2019;128: 14-43.
35. Rolls ET. The cingulate cortex and limbic systems for emotion, action, and memory. Brain Struct Funct 2019;224:3001-18.
36. Altenmüller E, Siggel S, Mohammadi B, Samii A, Münte TF. Play it again, Sam: Brain correlates of emotional music recognition. Front Psychol 2014;5:54522.
37. Klostermann EC, Loui P, Shimamura AP. Activation of right parietal cortex during memory retrieval of nonlinguistic auditory stimuli. Cogn Affect Behav Neurosci 2009;9:242-8.

How to cite this article: Ghosh A, Singh S, Monisha S, Jagtap T, Issac TG. Music and the aging brain – Exploring the role of long-term Carnatic music training on cognition and gray matter volumes. J Neurosci Rural Pract. 2024;15:327-33. doi: 10.25259/JNRP_605_2023