Auditory and Vestibular Research

Enhancing Auditory Spatial Perception through Music: Interplay Between Musical Aptitude and Training

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Highlights:
Musical aptitude aids in auditory spatial perception, despite lack of formal training
formal training benefits are realised in complex spatial task in musicians

Abstract
Background and aim: Musicians can detect changes in minute aspects including pitch, timing, and loudness, all of which assist in auditory spatial perception. This study hypothesized that non-musicians with musical aptitude might display spatial skills comparable to trained musicians, and superior to non-musicians without musical aptitude.
Methods: To test this hypothesis, we considered 101 participants in three groups: musicians (n=33, trained in classical music), non-musicians with good musical aptitude (NM-GA, n = 33) and non-musicians with poor musical aptitude (NM-PA, n = 35), selected based on convenience sampling. Music aptitude was assessed using Mini Profile of Music Perception Skills. A spatial test battery consisting of tests of binaural interaction - ITD (interaural time difference) and ILD (interaural level difference), and Virtual space identification test (VASI) were administered.
Results: Musicians and NM-GA demonstrated significantly lower ITD and ILD thresholds than NM-PA, suggesting the role of musical aptitude in sound lateralization. In VASI test, musicians scored highest, followed by NM-GA, who in turn had significantly higher scores than NM-PA, suggestive of further refinement of innate musical advantage due to training in musicians. Location specific analysis revealed NM-PA made significantly greater errors in R45, L45, R135, and L135 ($p<0.001$), often confusing them with extreme right (R90) or left (L90) locations.
Conclusion: Both innate musical aptitude and formal musical training contribute to enhanced spatial hearing abilities. While musicians and NM-GA exhibit superior ITD and ILD thresholds, musicians outperform NM-GA in VASI scores, indicating training refines complex spatial perception beyond natural aptitude.

Keywords: spatial hearing, musical aptitude, music training, virtual auditory space identification.

Introduction

Auditory spatial perception refers to the listener's capacity to perceive changes in the auditory signal, enabling them to localize the sound source or to estimate the distance between the source and the listener [1]. While the difference in the time of arrival (inter-aural time difference: ITD) and intensity (inter-aural level difference: ILD) of the sound between the ears, serves as a primary basis for spatial hearing in the horizontal plane, spectral cues play an important role for auditory spatial perception in vertical plane [2].

Although music and auditory spatial perception are distinct, they are similar in acoustic and cognitive aspects. Acoustically, these skills involve the detection of minute differences in pitch or loudness. Cognitively, music training demands a high working memory load and sustained attention, similar to spatial skills [3]. Also, spatial perception like music is controlled by memory and previous sound associations [4]. Empirical evidence suggests that the heightened auditory processing capabilities of trained musicians, including their enhanced sensitivity to subtle variations in pitch, timing, and intensity, may confer advantages in their spatial hearing sound compared to non-musicians [3]. Furthermore, music advantages are shown to percolate to other domains such as speech, language, and emotion [5].

Researchers have previously established a causal relationship between music and spatial task performance [6]. When listening to music, individuals experience space both metaphorically, through musical features evoking spatial concepts, and literally, by perceiving the spatial properties of sound sources [7]. Nisha et al. [8], demonstrated better performance of trained musicians over non-musicians in Virtual acoustic space identification test and binaural processing test (ITD and ILD). Interestingly, Upadhya et al. [9] showed that non-musicians with innate musical aptitude (rather than being formally trained for music) also showed significantly enhanced spatial hearing abilities, as evidenced by lower ITD and ILD thresholds, and higher VASI accuracy scores. This suggests that while formal musical training provides advantages in spatial processing, natural aptitude also contributes significantly to these abilities independent of training.

Along with musical training benefits, researchers have been exploring these transferrable benefits in untrained individuals who have pre-existing musical advantages or musical aptitude. These individuals referred to as ‘musical sleepers’ have been associated with an array of indispensable abilities, including working memory, selective attention, reading fluency, motor skills, and empathy [10,11]. Musical aptitude in non-musicians can be attributed to both nature and nurture interaction. Evidence has shown that musical aptitude is genetically determined and could also influence their inclination to practice, whereas an individual’s overall motivation, attention, general intelligence, conducive environment, and inclination towards music can contribute to better musical aptitude [12].

While general musical aptitude and training enhances auditory perception in general [8], and spatial perception in particular [9,13], it remains to be answered if these abilities work independently, how each contribute, and if there exists an interaction between them. With intrinsically proficient auditory systems, literature reports that non-musicians with good musical aptitude and enhanced frequency coding responses perform similarly to trained musicians [14]. The presence of such non-musicians with good aptitude can invariably affect the group differences in spatial processing tasks. Segregating musicians and non-musicians with good aptitude before their inclusion in auditory spatial tasks is essential because those with good musical aptitude might perform better in the experiments than actual non-musicians or perform at par with musicians while being considered non-musicians. In this study, we try to explore the role of musical aptitude, and musical training on auditory spatial skills using a battery of tests i.e. ITD, ILD, VASI. To disentangle these factors, we included three distinct groups: trained musicians and non-musicians with either good or poor musical aptitude. This design allows us to examine whether formal training, natural aptitude, or their combination most significantly impacts spatial hearing abilities, providing insight into the relative contributions of nature versus nurture in auditory spatial processing.

Methods

Participants

The Standard group comparison study was approved by the institutional review board (Ref: SH/AUD07/2022-23 dated 12.7.2022). Informed consent was obtained from all the participants involved in the study. Participants were provided with detailed information about the study's purpose and procedures, and they voluntarily agreed to participate by signing a consent form.

The study was conducted on 101 participants (aged 18-25 years), who were divided into three groups, through convenience non-probability sampling. Selected participants had normal hearing thresholds at octave frequencies (≤ 15 dB HL) and mean speech identification scores of 93.4 ± 3.6 %. All the participants of this study underwent Mini-PROMS test, which is a test of musical ability. The Mini-PROMS test is a concise online assessment tool designed to objectively evaluate musical ability within a brief timeframe, typically spanning 20 to 25 minutes. The test is divided into 4 sections - tonal, qualitative, temporal, and dynamic. Each subtest is designed to measure different psychoacoustical aspects involved in music perception: tonal (melody, pitch), qualitative (timbre, tuning), temporal (rhythm, rhythm-to-melody, accent, tempo), and dynamic (loudness). It employs a discrimination task to elicit responses. The maximum attainable score for this test is 36, whereas the stipulated criterion for classifying individuals as possessing good musical ability is greater than or equal to 18.
Participants were grouped based on their musical training and musical aptitude. Group I consisted of 33 trained musicians (mean age: 25.47 ± 2.35; 18 Females; 15 Males) from Raghuleela school of music, Mysore, India. The musicians were trained in vocal Indian classical music for a minimum of 10 years (mean number of years of training 12.54 ± 1.27 years), and practised one hour of playing music, for at least five days a week. The rationale for a sustained practice, of minimum ten years is consistent with the objective of the study that intensive training, rather than innate talent alone —was crucial for reaching expert performance in music. A minimum ten years of practice with one hr of training was found consistent with was found consistent with the Ericsson et al. [15] study, wherein he found 10,000 hours (of deliberate practice roughly 1 hour of focussed practice for 10 years) is needed for reaching expert performance in music. This view is supported by Wright et al. [6], who found that musicians have an advantage on a spatial-hearing task (ILD inn their study) only when they are trained for more than 10 years. The untrained participants were age-and gender matched volunteers from bachelor's degree at the institute, who scored ≥ 18 on Mini-Proms were considered as non-musicians with good musical aptitude (NM-GA) and grouped under Group II (n = 33, mean age: 23.65 ± 1.59 y; 17 Females; 16 Males), while Group III (n = 35, mean age: 21.74 ± 1.84 y; 20 Females; 15 Males) consisted of non-musicians who scored <18 on Mini-Proms , and were classified as non-musicians with poor musical aptitude (NM-PA).

Auditory spatial processing tests

A spatial test battery was administered to all three groups. Virtual acoustic space identification test (VASI), and tests of binaural interaction i.e., ITD (interaural time difference) and ILD (interaural level difference) were performed on each participant. All the test stimuli were presented through the circumaural headphones (Sennheiser HD 280 PRO, Wedemark, Germany), using appropriate equalisation techniques which provided good azimuth replication that was comparable to the spatial hearing performance of individuals with normal hearing in free-field environments [16].

Interaural time difference (ITD) and interaural level difference (ILD) thresholds

ITD and ILD threshold tests were administered using the psychoacoustics toolbox [17] of the MATLAB software - version R2019a (Mathworks Inc., Natick, USA). The source code for the psychoacoustic toolbox is a freely available in the university of Padova website (https://dpg.unipd.it/en/mlp/psychoacoustics). The tool has been used by several researchers for psychoacoustical experiments worldwide and there is vast empirical evidence regarding the utility of the tool [18,19]. The tool implement various adaptive procedures for threshold estimation, such as Staircase, Parameter Estimation by Sequential Testing (PEST), and maximum likelihood procedure (MLP) methods [17]. In this toolbox, a custom MATLAB code for generating the stimuli, and adaptively varying the time of arrival (ITD) or intensity (ITD) of the signal between the two ears (as suited to the experiment) was configured. Staircase psychometric procedure, with step size set to 2 dB for ILD, and factor of 2 for ITD, 8 reversals for termination, and converging at 4 reversals for threshold estimation were also configured. Both ITD and ILD tests were carried out using 3 interval 2 alternative forced choice method, using two-down one-up staircase procedure converging at 70.7% of the psychometric function [20]. Each trail consisted of three white noise bursts of 250 ms duration. Prior to testing, the level of the stimuli was calibrated to 65 dB SPL using a sound level meter (Bruel and Kjaer 2270, Naerem, Denmark) connected to a manikin ear (Knowles Electronics Manikin for Acoustic Research, KEMAR model 45-BB, Holte, Denmark).
In a trial comprising of three stimuli, two were standards stimuli, whereas one stimulus was deviant. The standard stimuli were 250 ms WBN that produced mid-line lateralization, owing to similar intensity and onset time in both channels. The third stimulus was a variable stimulus that had inherent differences in intensity (ILD) or time (ITD) in the right channel. The order of the variable interval was randomly designated in each trial. Participants were

instructed to identify the variable stimuli in each trail (based on the lateralization it produced) and respond by pressing the stimuli number on the keyboard. The initial trials consisted of large ITD (starting step size – 20 ms) or ILD (starting step size – 10 dB) increments, which decreased adaptively based on the response of the participant. On two correct identifications of the variable stimuli, the step size of variable stimuli for ITD reduced by a factor of half (eg. 10 ms, on two correct identifications of 20 ms variable stimuli). Similarly, for ILD task, it reduced by 2 dB for first 5 levels, later on it was reduced by 1 dB. However, if the participant registered an incorrect response on any trial, the ITD was doubled or the ILD increased by 2 dB. The change from correct identification to incorrect response is considered as response reversal. The test was terminated after 10 reversals and the average of the last 4 reversals was considered for the estimation of the ITD and ILD thresholds.

Virtual auditory space identification test

The virtual acoustic space identification (VASI) test is a closed field test of lateralization performed using headphones [21]. VASI stimuli were generated using white noise of 250 ms convolved with HRTF database available in Slab 3D version 6.7.3 [22]. Eight spatial locations within the head were used in VASI i.e., mid-line front (0° azimuth), 45° azimuth toward the right ear (R45), 90° azimuth toward the right ear (R90), 135° azimuth toward the right ear (R135) mid-line back (180° azimuth), and 135° azimuth toward the left ear (L135), 90° azimuth toward the left ear (L90), 45° azimuth toward the left ear (L45). The overall stimuli intensity was maintained at 65 dB SPL.

Stimuli at each location were randomly presented 10 times each, thus making a total of 80 stimuli for each participant. Paradigm software was used for the stimulus delivery and response acquisition, wherein the participants were asked to click on the graphical user interface (dummy head as shown in Figure 1) corresponding location, which emitted the sound. Output data was analysed by constructing a confusion matrix (stimulus-response contingency grid) by adopting MATLAB script (confusion matrix for syllable identification [23]). The total number of correct responses for each location and overall VASI scores were obtained from the confusion matrix.

Statistical analysis

IBM Statistical Package Social Sciences (SPSS) version 25.0 BM Corp., Armonk, NY, US) was used for statistical analysis. Shapiro-Wilks test of normality was used to determine if the data were normally distributed. Based on the results of Shapiro Wilks, the parametric test MANOVA was performed to judge the group differences (if any) in spatial performance among the musicians, NM-GA, and NM-PA. This was followed by post-hoc independent *t* tests with Bonferroni corrections to study pairwise comparisons.

Results

The Mini-PROMS score of all the three groups along with their standard deviation is mentioned in Table 1. Group I showed the highest scores in Mini-PROMS test (24.01 ± 2.71), followed by Group II (20.63 ± 2.39) and Group III (15.14 ± 1.79).

The mean and standard deviation of ITD, ILD and VASI scores for all three groups are presented in Figure 2. ITD and ILD thresholds were lowest for musicians (Group I), followed by NM-GA (Group II) and the poorest for NM-PA (Group III). Shapiro-Wilks test showed a non-normal distribution for ITD ($p < 0.05$), whereas ILD and VASI showed normal distribution ($p > 0.05$). Kruskal-Wallis H test on ITD revealed a significant main effect of the group [$\chi^2(2) = 23.31$ $p < 0.001$, $\eta_H^2 = 2.32$]. Further Dunn Bonferroni test revealed significantly higher ITD thresholds in NM-PA group compared to musicians ($p < 0.001$) and NM-GA ($p = 0.01$). The ITD thresholds of the latter two groups did not differ significantly (adjusted $p = 0.06$). Multivariate analysis of variance test (MANOVA) revealed a significant main effect of the group on ILD thresholds [$F(2,98) = 23.03$, $p < 0.001$, $\eta_p^2 = 0.32$] and overall VASI scores [$F(2,98) = 56.50$, $p < 0.001$, $\eta_p^2 = 0.54$]. Bonferroni test on ILD thresholds showed a similar trend as ITD, with musicians and NM-GA demonstrating comparable ILD thresholds ($p = 0.14$), both of which were significantly lower (better) compared to NM-PA ($p < 0.001$). However, Bonferroni test on VASI scores revealed an interesting finding, with musicians scoring significantly higher than NM-GA ($p < 0.001$), who in turn had higher VASI scores compared to NM-PA ($p = 0.02$).

Table 2 shows the target-response grid for all three groups. Through the average response scores from all the groups, it can be seen that NM-PA (Bottom black panel) exhibited higher confusion in VASI compared to NM-GA (middle grey panel) and musicians (top white panel). The judgment errors of front-back and back-to-front were higher in all the groups. Further location-specific analyses of VASI scores using MANOVA is shown in

Table 3. MANOVA on location-wise VASI scores showed the main effect of group only for partially lateral right and left locations in frontal plane [R45 - $F(2,98) = 30.78$, $p < 0.001$, $\eta_p^2 = 0.39$; L45 - $F(2,98) = 26.57$, $p < 0.001$, $\eta_p^2=0.35$] and rear plane [R135 - $F(2,98) = 21.29$, $p < 0.001$, $\eta_p^2 = 0.30$; L135 - $F(2,98) = 23.39$, $p < 0.001$, $\eta_p^2 = 0.32$], midline rear plane [180^0 - $F(2,98) = 6.26$, $p < 0.05$, $\eta_p^2 = 0.11$], while no main effect of group was seen ($p > 0.05$) in extreme lateral (R90, L90) planes and mid-line frontal (0^0) plane. Results of post-hoc Bonferroni test depicted in Figure 3, revealed that musicians performed significantly better i.e. had higher VASI scores ($p < 0.001$) at these partial lateral locations compared to NM-GA and NM-PA on, while there was no difference ($p > 0.05$) in VASI scores of the two non-musician groups at these locations. The frontal lateral (R45, L45) and rear lateral (R135, L135) locations were usually confused as corresponding extreme right (R90) or left (L90) virtual locations.

Discussion

The spatial hearing differences due to musical aptitude and musical training was explored in this present study. After establishing better mean scores of musical abilities of musicians in Mini-PROMS test (Table 1), compared to NM-GA (Group II), and NM-PA (Group III), the study focused on disentangling the interplay of aptitude and training on tests of spatial acuity i.e. ITD, ILD, and VASI.

Results revealed significantly better ITD and ILD thresholds among musicians (Group I) and NM-GA (Group II) compared to NM-PA (Group III) (Figure 2). There was no significant difference in both ITD and ILD thresholds between the former two groups. While research consistently demonstrates that musicians exhibit superior performance than non-musicians with better binaural thresholds (ITD, ILD) thresholds among musicians [8,24], the finding of present study extends this finding to the non-musicians who have innate musical abilities i.e. NM-GA. Studies on adults trained musicians prove that musical advantages on ILD discrimination is seen when musicians undergo extensive music training ($\geq$ 10 years), early onset of training ($\leq$7 years), and its continued practice [6]. Extending these findings, the present study found that even non-musicians (Group II- NM-GA) can exhibit superior binaural sensitivity. This finding suggests that structured training is not the sole reason to improved binaural processing, but alternative mechanisms are responsible for auditory plasticity beyond formal musical instruction. One such mechanism might be nature bestowed heightened musical abilities, and hence improved auditory processing in cluster of participants, known as musical sleepers [25,26]. Sampath and Neelamegarajan [30] demonstrated that children with innate musical abilities (i.e., musical sleepers) show improved ILD processing, indicating early advantages in auditory spatial cues critical for sound localization.

Interestingly, the results of VASI test revealed a new finding in the interplay of the aptitude and training in spatial hearing. Significant differences among all three groups are noted in overall VASI scores, with the musicians showing higher VASI scores than NM-GA, who in turn had better VASI scores than NM-PA (Figure 2). This finding proves that while inherent musical aptitude abilities can improve auditory spatial perception (VASI scores), these abilities can be additionally refined by the musical training. This finding supports and extends the study by Upadhya et al. [9], who found a positive correlation between musical aptitude scores (MINI-PROM) and VASI in non-musicians. Although all the participants in their study were non-musicians, the group with better musical aptitude (akin to NM-GA in the current study) scored significantly higher VASI than the non-musicians with poor MINI-PROM scores. Extending these findings, the present study proved that musical training confers a greater advantage over good musical aptitude abilities. This supports the view that spatial advantages conferred from musical skill arises from both biological pre-dispositions and formal training, with training amplifying innate auditory capacities. Thus, both nature and nurture synergistically shape spatial hearing in musically inclined individuals.

Location specific analysis of VASI test highlighted other interesting findings on the nature of spatial errors seen in musical aptitude (Group II and Group III) and training (Group I) groups (Figure 3). The judgment errors of front-back and back-to-front were high in all the groups (Table 2), as participants had to rely only on spectral cues in these planes due to limited role of ITD and ILDs at mid-line. The front-back ambiguity is previously noted in literature by a few other authors [27,28]. Another finding hints that musical advantages in VASI, does not spread equally to all 8 virtual locations tested in the study (Table 3). The spatial advantage conferred by musical training is most evident in partial lateral plane locations such as R45, L45 (frontal) and R135, L135 (rear), rather than at the extreme lateral positions (R90, L90). Sound localization at R90 and L90 primarily relies on monaural cues from the near ear—specifically, higher intensity and earlier arrival time—making lateralization relatively straightforward due to strong interaural differences [29]. In contrast, identifying sounds at intermediate lateral positions (R45, L45, R135, L135) requires finer auditory resolution, involving subtle spectral cue processing [29].

Another intriguing finding is that musicians with significant musical training exhibited a clear spatial identification advantage at the rear mid-sagittal plane (180°), whereas no such advantage was observed at the frontal mid-sagittal plane (0°). This difference arises despite both angles lying on the midsagittal plane and reflects the varying nature and complexity of auditory cues involved in sound localization at these positions. At 0°, localization is supported by precise and highly reliable binaural cues—interaural time and level differences—that provide clear spatial information [30], making the task comparatively easy and resulting in similar performance for musicians and non-musicians. In contrast, at 180 degrees, these binaural cues are ambiguous or diminished, requiring listeners to depend more on complex spectral cues, which are more difficult to interpret [31]. Musicians, through training, develop enhanced sensitivity to these spectral cues [32], and refined auditory spatial processing [6], enabling them to better disambiguate rear sound sources, thus showing a distinct advantage at 180^0. Moreover, as spatial resolution decreases for sounds away from the frontal plane [33], the heightened auditory skills cultivated by musicians become particularly beneficial for challenging rear plane localization tasks. This explains why musical training advantages are consistently manifested across all three rear-plane azimuth positions (180°, R135, and L135) in VASI task of the current study.

Implications and future directions

This study defines a positive impact of musical aptitude on auditory spatial perception, which can be further enhanced by musical training. The advantages of musical training in spatial processing can have promising outcomes on special population with auditory spatial processing disorders like Auditory neuropathy spectrum disorder (ANSD) and central auditory processing disorder (CAPD). In addition, spatial deficits have been identified in individuals with schizophrenia [34] and those experiencing visuospatial neglect [35]. In such populations, the integration of musical training or music therapy into rehabilitation programs could enhance spatial perception. Moreover, individuals with hearing impairments often exhibit altered auditory spatial perception . Incorporating musical training or music therapy, alongside auditory verbal therapy, may prove valuable in enhancing spatial perception.

Future research on spatial perception should account for individual differences in musical aptitude, as these can significantly influence outcomes. One important limitation of this study is that musical aptitude was not measured in musicians prior to their training. As a result, it is difficult to determine the extent to which observed differences in spatial abilities are attributable to pre-existing musical aptitude versus musical training itself. Although Mini-PROMS scores provide a measure of musical aptitude at time of study, this measure, being administered only once, may not capture baseline differences between groups. This highlights the importance of assessing musical aptitude in all participant groups—ideally both before and after musical training—in future studies to allow for a more accurate depiction of group differences. A longitudinal design would also help clarify the causal relationship between musical training, aptitude, and auditory spatial processing. The presence of non-musicians with high musical aptitude may reduce observable group differences as they exhibit better spatial processing skills, so caution is needed while selecting control group in psychoacoustic experiments. Therefore, in studies comparing musicians and non-musicians, musical aptitude should be treated as a key variable, as it may independently enhance spatial processing abilities regardless of formal training.

Conclusion.

The study highlights that both musical aptitude and formal training contribute significantly—but differently—to auditory spatial processing. While enhanced ITD and ILD thresholds in both musicians and non-musicians with good aptitude suggest a nature-driven advantage, superior VASI scores among musicians underscore the added benefit of musical training in refining spatial perception. Notably, training enhances processing at complex spatial locations requiring fine spectral discrimination and attentional control. These findings provide evidence for the interplay between musical training and musical aptitude on the spatial hearing skills (ITD, ILD, VASI), and advocate for considering musical aptitude as a key variable in future auditory spatial research.

Declarations

1. Authors' contributions

All the authors approved final manuscript
RB: Conceptualization, Project administration Formal analysis, Visualization, Writing-review & editing; SU: Data curation, Formal analysis, Investigation, Methodology, Visualization, Writing-original draft; RJ: Data curation, Formal analysis, Investigation, Writing-review & editing; NKV: Conceptualization, Methodology, Project administration, Software, Supervision, Visualization, Writing-review & editing

2. Competing interests

The authors declare no competing interests that could potentially bias the research or create conflicts of interest.

3. Funding

There was no source of any external funding for the research.

4. Acknowledgements

We would like to express our gratitude to the HoD Audiology for her support throughout this research. We also acknowledge Director of All India Institute of Speech & Hearing, affiliated to the university of Mysuru for providing access to necessary resources that facilitated this study. Sincere thanks to all the participants, who volunteered for the study.

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Table 1: Mini-PROMS test scores of three groups.

Groups	**N**	**Minimum scores**	**Maximum scores**	**Mean**	**Std. Deviation**
Group I - Musicians	33	19.50	28.00	24.01	2.71
Group II – NM-GA	33	18.00	27.00	20.63	2.39
Group III – NM-PA	35	10.50	17.50	15.14	1.79

Note: NM-GA : Non-musician with good musical aptitude; NM-PA : Non musician with poor musical aptitude.

Table 2: Target-response grid for three groups. . Values written in bold are correct responses of that particular location (Max score per location – 10).

Target VAS location	***Groups***	***Response VAS location***							
		R45	R90	R135	180	L135	L90	L45	0
R45	Musicians	**7.63**	0.57	1.40	0.10	0.00	0.00	0.00	0.30
	NM-GA	**5.30**	1.99	1.88	0.08	0.08	0.41	0.00	0.07
	NM-PA	**4.26**	2.39	2.12	0.13	0.07	0.72	0.00	0.00
R90	Musicians	1.42	**6.60**	2.34	0.00	0.00	0.00	0.00	0.00
	NM-GA	2.90	**6.40**	0.45	0.09	0.08	0.00	0.15	0.32
	NM-PA	4.17	**5.60**	3.30	0.07	0.00	0.00	0.00	3.30
R135	Musicians	2.85	1.76	**8.39**	0.00	0.00	0.00	0.00	0.00
	NM-GA	2.37	1.37	**5.63**	0.55	0.08	0.00	0.00	0.00
	NM-PA	1.84	2.16	**5.31**	0.50	0.19	0.00	0.00	0.00
180	Musicians	0.00	0.00	0.12	**8.57**	0.12	0.00	0.00	1.19
	NM-GA	0.08	0.97	0.59	**7.20**	0.98	0.00	0.00	1.18
	NM-PA	0.13	0.29	0.68	**6.96**	0.38	0.00	0.00	1.56
L135	Musicians	0.00	0.00	0.00	1.28	**8.57**	0.15	0.00	0.00
	NM-GA	0.00	0.00	0.00	1.63	**5.71**	1.47	1.07	0.12
	NM-PA	0.40	0.00	0.00	2.07	**5.57**	1.88	0.49	0.00
L90	Musicians	0.00	0.00	0.00	0.00	1.13	**7.51**	1.03	0.33
	NM-GA	0.00	0.00	0.00	0.00	2.34	**6.75**	1.01	0.00
	NM-PA	0.00	0.00	0.00	0.00	0.08	**6.34**	3.08	0.58
L45	Musicians	0.00	0.00	0.00	0.00	0.75	1.93	**7.61**	0.53
	NM-GA	0.00	0.00	0.00	0.00	0.65	1.75	**5.00**	0.60
	NM-PA	0.00	0.00	0.00	0.00	0.80	2.46	**4.81**	1.93
0	Musicians	0.11	0.00	0.00	0.33	0.11	0.00	0.22	**6.66**
	NM-GA	0.08	0.00	0.15	0.76	0.16	0.53	0.84	**6.27**
	NM-PA		0.00	0.00	0.00	0.94	0.06	0.16	**6.51**

Note: NM-GA : Non-musician with good musical aptitude; NM-PA : Non musician with poor musical aptitude.

Table 3: MANOVA result of location specific scores of VASI test for main effect of groups..

VAS Location	MANOVA F (2,98) =	Significance p =	Effect size, Partial Eta Squared, η_p^2 =
R45	**30.78**	**<0.001**	**0.39**
R90	2.53	0.09	0.05
R135	**21.29**	**<0.001**	**0.30**
180	**6.26**	**0.03**	**0.11**
L135	**23.39**	**<0.001**	**0.32**
L90	3.19	0.06	0.04
L45	**26.57**	**<0.001**	**0.35**
0	0.26	0.77	0.01

Note: The numbers in bold represent VAS locations with significant group effects.

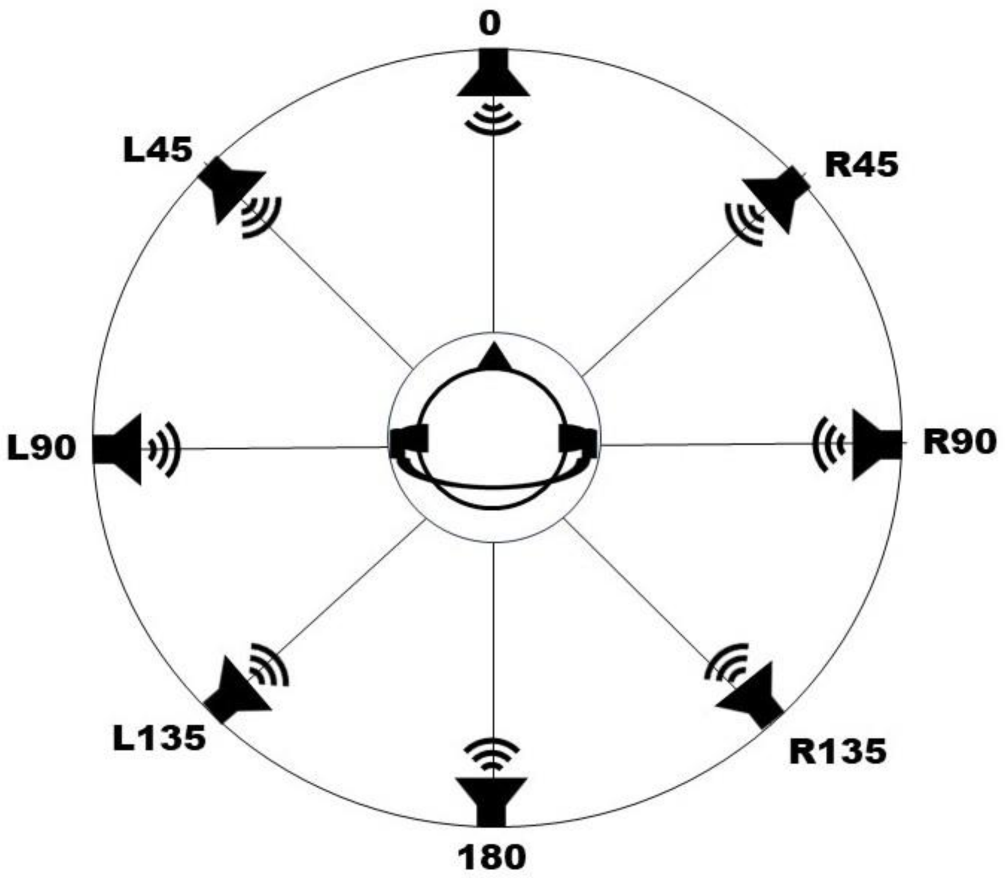

Figure 1: User interface with dummy head locations used for VASI stimulus presentation and response acquisition.

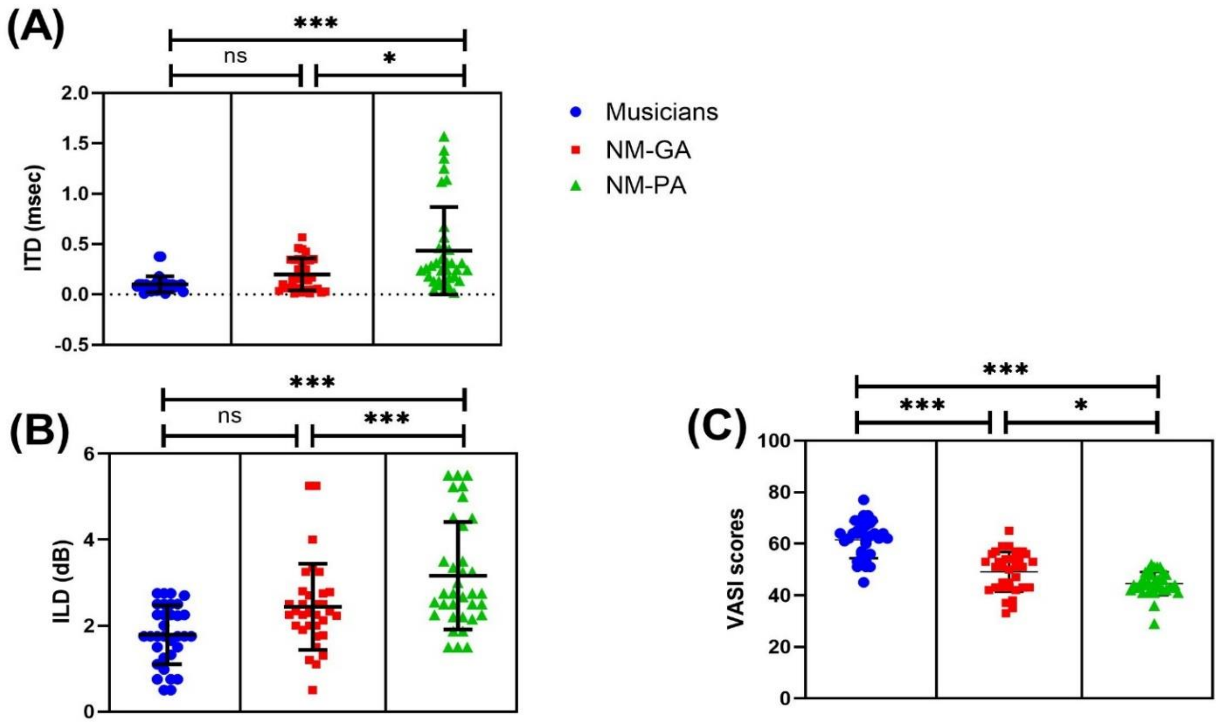

Figure 2: Comparison of mean (middle line), and standard deviation (error bars) of (A) Interaural time difference in milliseconds B) Interaural level difference in dB, and (C) VASI scores across three groups.
Note: NS indicates not significant; *** indicates $p < 0.001$; * indicates $p < 0.05$

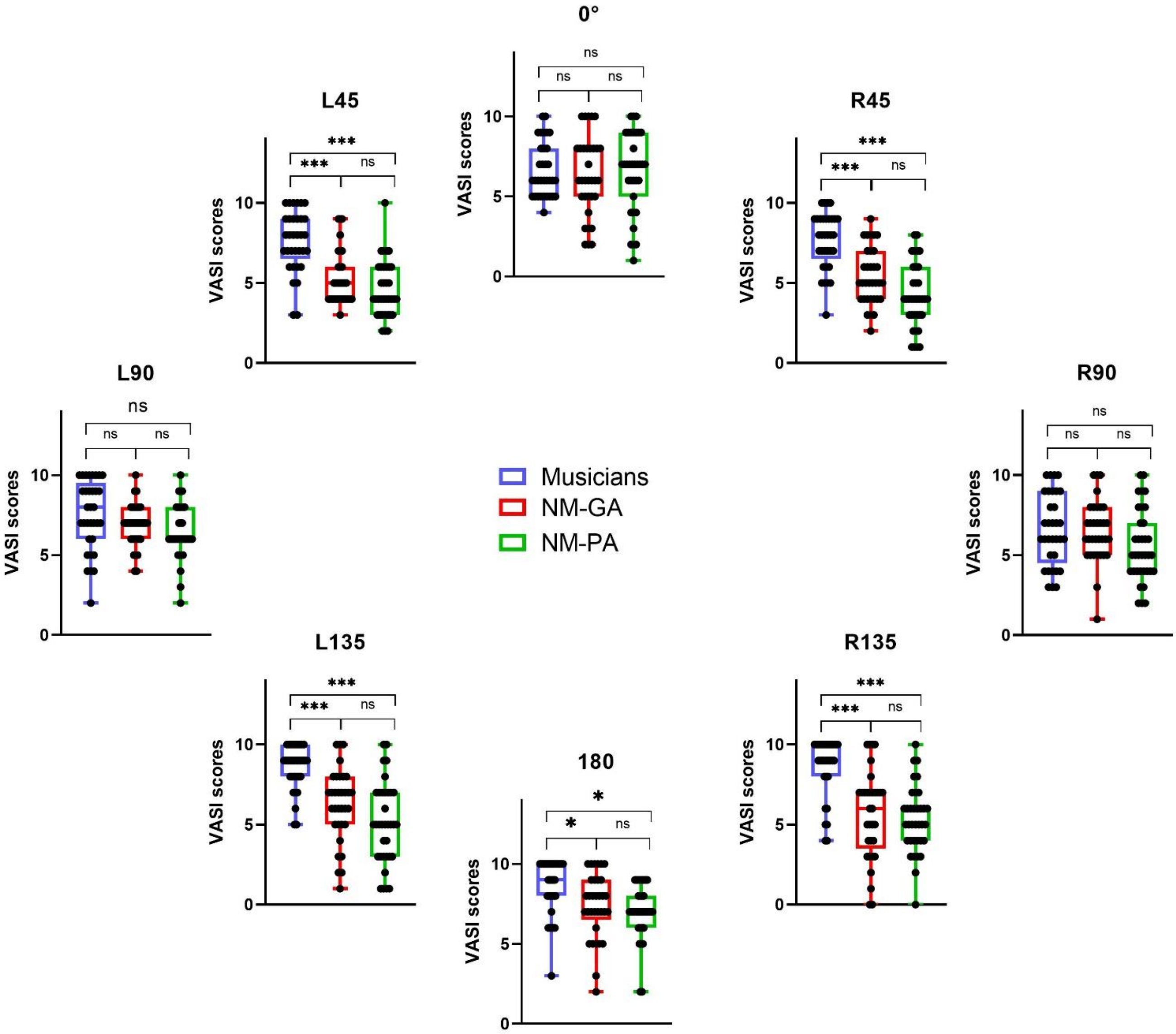

Figure 3: VASI scores of three groups - Musicians (Group I) – represented in blue, NM-GA (Group II) – represented in red and NM-PA (Group III) – represented in green, for different locations: mid-line front (0°), 45° azimuth toward the right ear (R45), 90° azimuth toward the right ear (R90), 135° azimuth toward the right ear (R135) mid-line back (180° azimuth), and 135° azimuth toward the left ear (L135), 90° azimuth toward the left ear (L90), 45° azimuth toward the left ear (L45).

Note: NS indicates not significant; *** indicates $p < 0.001$