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Differential advantages of musical backgrounds on binaural integration and interaction skills in instrumentalists, vocalists, and non-musicians

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A B S T R A C T

Background: Musical perception requires a host of skills. Instrumental musicians place greater emphasis on motor coordination, whereas vocal musicians rehearse vocal sounds. The study explored the differential advantages of musical background on binaural integration and interaction in musicians (instrumentalists, vocalists) and compared them with age-matched non-musicians.

Methods: Eight six participants aged 20–40 y with normal hearing sensitivity were subjected to binaural tests using a standard group comparison research design. The participants were segregated into three groups – Group 1 included instrumentalists (n = 26, mean age: 17.73 ± 2.83 y), while Group 2 and Group 3 consisted of vocalists (n = 30, mean age: 19.30 ± 2.47 y) and non-musicians (n = 30, mean age: 18.20 ± 3.02 y) respectively. The binaural processes namely integration (Dichotic syllable test, DST; and virtual acoustic space identification - VASI) and interaction (Interaural difference thresholds for time and level: ITD & ILD), were administered on all the participants.

Results: Statistical analyses showed the main effect of musicianship. Bonferroni pair-wise test revealed that the musicians (instrumentalists and vocalists) outperformed ($p < 0.05$) non-musicians in all the tests. The differential advantage of the musical background was seen on the binaural integration test with instrumentalists performing better in the VASI test compared to vocalists, and vice-versa for DST. No difference was observed in interaction tasks (ITD & ILD) between vocalists and instrumentalists ($p > 0.05$).

Conclusion: Musical background-induced differential advantages can be reasonably noted in the binaural skills of instrumentalists and vocalists (compared to non-musicians).

1. Introduction

Music performers in all traditions bring music to life by striking emotions conveyed through their vocal apparatus or by playing instruments. Broadly speaking, musicians can be classified as belonging vocalists and instrumentalists, based on their preferred backgrounds (Kumar and Krishna, 2019). The primary distinction between instrumentals and vocalists is their manual and acoustical control of instruments and vocal apparatus. Literature points out other acoustical and physiological differences (Kumar and Krishna, 2019) between vocal and instrumental musicians. Physiologically, the vocalist's enunciation, rendering, and articulation are the cornerstone of vocal music. On the other hand, the music conveyed through instruments focuses mostly on composition without lyrics, although non-articulate vocal input might be a complementary element. In stark contrast to instrumental musicians who focus more on non-verbal sounds, vocalists practise speech sounds more. Most of the instrumental music is based on highly linear resonators, which determine the playing fundamental frequency, while their resonances determine the pitch. On the other hand, for the vocalists, the resonances in the vocal tract govern their pitch. While acoustic parameters such as pitch, duration and loudness are always independently adjustable in instrumental music, vocalists control the sub-glottal pressures and vocal fold parameters in-order to change acoustic parameters. Altering several physiological parameters is required to change pitch and loudness in vocalists (Kumar and Krishna, 2019).

In addition, differences in musicians belonging to different

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backgrounds are also evident in brain dichotomy (left and right dominance). Individuals with instrumental musical abilities tend to have right hemisphere dominance (Jantzen et al., 2014), while vocalists may be hypothesized to have left hemisphere dominance due to linguistic elements involved in singing. Background music score (right hemisphere function) for vocalists and appreciation of written musical notes (left hemisphere function) by instrumentalists are overlapping tasks, leading to whole-brain activity. Whole brain activity refines binaural processing due to the inter-hemispheric interaction for the musician groups (Krzyżak, 2021), which are otherwise not so appreciable in non-musicians. Therefore, we may postulate that dichotomy in hemispheric specialization between musicians belonging to different musical backgrounds may lead to their varied skills in spatial perception, pitch discrimination, and loudness discrimination.

The dichotomy between the left and right hemispheres in terms of the musical event is supported by several psychophysiological and neuroimaging works (Berlin et al., 1973; Mazziotta et al., 1982), which provide evidence of laterality for verbal and non-verbal sounds. The basis for this dichotomy is the idea that the left hemisphere controls the analyses of temporal fine structure, which is enhanced during verbal stimulation. In contrast, the right hemisphere is specialised at analysing the frequency of the stimulus and has greater activation when presented with nonverbal stimuli. (Brancucci et al., 2005; Epstein, 1998; Ghazanfar and Hauser, 1999; Halpern, 2001). The linguistically loaded information while singing in vocalists might lead to the left brain activity, contrasting with instrumentalists who might have predominant role of right brain activity for processing musical notes.

Musical training, in general can improve auditory fitness in the brain (Kraus and Chandrasekaran, 2010) and has been shown to improve specific central auditory processing skills (Bianchi et al., 2019; Braz et al., 2021; Kahraman et al., 2021; Marozeau et al., 2013; Mishra et al., 2015; Zendel et al., 2015; Zhang et al., 2021). Differential auditory processing skills have been demonstrated in instrumentalists belonging to different musical genres (Nikjeh et al., 2008). Cortical processes such as speech perception in noise and auditory memory skills are reported to be better in vocalists compared to instrumentalists (Kumar and Krishna, 2019; Priyanka, 2019). Based on these differences, it might be logical to hypothesize that the complexity of auditory processes (temporal, intensity, and spectral) involved in learning and perceiving vocal and instrumental music can be different. Recently, comparative research on central auditory processing in vocalists and instrumentalists groups showed that instrumentalists had obtained significantly higher scores in frequency pattern perception test (verbal) compared to vocalists, while both the groups (instrumentalists and vocalists) had comparable scores in other tasks including random gap detection test, synthetic sentence identification with ipsilateral competing message, and frequency pattern test-humming (Paoliello et al., 2021). In contrast, Kumar et al. (2014) found that the vocalists and instrumentalists in their study did not show any group differences in gap detection thresholds, duration discrimination test, duration pattern test, and modulation detection thresholds, indicative of similarities in auditory temporal functioning in the two musically trained groups. No group differences between vocalists and instrumentalists were seen on working memory tasks such as forward and backward digit span, and verbal retention for meaningful and non-meaningful pairs (Kumar and Krishna, 2019).

The present study aimed to explore if the differential advantages of musical training can be extended to binaural processes. Binaural hearing refers to integrating and interpreting incoming sounds from both ears, and is a critical mechanism for sound localization, auditory stream segregation, and hearing in difficult situations (Avan et al., 2015; van der Heijden et al., 2019). The major cues for localization in the horizontal plane are interaural time differences (ITDs) and interaural level differences (ILDs), which stem from time and level differences of the sound signal at the nearer ear (compared to the farther ear). The importance of these cues for spatial hearing has been addressed by the duplex hypothesis, which claims that the localization of auditory stimuli is caused by two distinct mechanisms, the first uses information about ITDs which operates at low frequencies and the second uses information about ILDs that predominate at high frequencies (Blauert, 1997). Another important cue for spatial hearing is the spectral cues of the pinna, which can be analysed by virtually synthesized stimuli (Nisha & Kumar, 2017). Musicians have been reported to have better binaural perception (ITD thresholds, ILD thresholds, virtual auditory space identification - VASI scores and subjective ratings) when compared to non-musicians (Nisha et al., 2022). Analyzing interaural variations aids in the differentiation of sound sources, and helps speech perception in noise (Parbery-Clark et al., 2011; Strait et al., 2012; Strait and Kraus, 2014). While the ITD, ILD, and VASI tests assess binaural interaction skills, the binaural integration is tested using dichotic syllable test (DST), which involves presenting syllables to both ear simultaneously and integrating them.

In light of the advantages of musical training in general for auditory processing, and differences in skills owing to musical backreounds in particular, we hypothesized that binaural processing involving processes of binaural interaction (ITD, ILD and VASI) and binaural integration (DST) can be differentially affected by instrumental or vocal training in music. The current study aimed to understand if musical backgrounds induce differential abilities in binaural integration and interaction abilities in instrumentalists and vocalists. An attempt to compare the performance of the former groups (instrumental and vocalists) with a control group i.e. non-musicians, is also done.

2. Methods

2.1. Participants

A standard group comparison research design was followed. All the participants underwent audiological evaluation and had hearing sensitivity within normal limits, which was complemented by an A-type tympanogram and normal ipsilateral and contralateral reflex thresholds at 0.5 and 1 kHz. Participants with otological complaints, hearing loss and neurological complaints were excluded from this study.

Eighty six right-handed normal hearing individuals were recruited (air and bone conduction thesholds within 15 dB HL, Goodman, 1965) aged between 20 and 40 years. The recruited participants of the study were divided into three groups – Group 1 comprising instrumentalists (n = 26, mean age: 17.73 ± 2.83 y, 12 males, 14 females), Group 2 comprising vocalists (n = 30, mean age: 19.30 ± 2.47 y, 13 males, 17 females), and Group 3 comprising non-musicians (n = 30, mean age: 18.20 ± 3.02 y, 13 males, 17 females). The participants included in Group 1 had professional instrumental musical training with a minimum of 3 years (mean experience = 4.58 ± 1.31 years). The instrumentalists included were those using Keyboard, Veena (Indian string instrument), and Violin. Participants included in Group 2 had received formal vocal musical training in Indian classical music for at least 3 years, with a mean experience of 5.98 years. Participants in Group 3 had not received any professional training in the field of music. All three groups had minimally participated/played instruments in orchestras/musical concerts (not more than three concerts in a year). The participants in the music training schools (vocal and instrumental) in the city of Mysore, India were identified. A google form containing the demographic details (age, gender, number of years of experience) and consent to participate were circulated to the musicians (Group I & Group II) who were enrolled for the coaching music classes in these schools. Based on the information collected, those participants who satisfied the inclusion criteria were recruited for the study. The study followed the recommendations formulated by the institutional review board and guidelines given in bio-behavioral research for human studies (Venkatesan, 2009).

2.2. Procedure

Preliminary testing for the inclusion included pure-tone audiometry, Tympanometry and Reflexometry. Hearing thresholds in the air and bone conduction modes were evaluated using the modified Hughson-Westlake approach. Inventis Piano audiometer (Inventis, 35127 Padova, Italy) was used for both the air and bone conduction measurements. The air and bone conduction thresholds were obtained using Telephonics TDH-39P supra-aural headphones (Telephonics, Farmingdale, NY, USA) and Radioear B71 bone vibrator (Radioear, KIMMETRICS, Smithsburg, MD, USA) respectively. While air conduction testing was performed in octaves ranging from 0.25 to 8 kHz, bone conduction thresholds were obtained from 0.25 to 4 kHz. All the participants included in the study had bilateral hearing sensitivity within normal limits i.e. the pure tone thresholds of all the participants were less than 15 dB HL for both air and bone conduction and an air-bone gap of $\leq$ 10 dB HL (Goodman, 1965). To screen for conductive pathology, GSI Tympstar middle ear analyzer (GSI-61; Grason Stadler Inc, Milford, NH, USA) was used. Ipsilateral and contralateral acoustic reflex thresholds at 0.5 and 1 kHz were measured and participants with A type Tympanogram with normal ipsilateral and contralateral reflex thresholds were considered for the study (Jerger, 1970).

The music perception abilities questionnaire (Neelamegarajan et al., 2017) was adminstered on all the participants. The questionnaire consisted of 28 questions. The elicited binary (yes or no) response of the participants on music perception in domains related to pitch awareness, pitch discrimination, timbre identification, melody recognition, and rhythm perception were obtained. It could be completed in about 10–15 min. Each question received a score of one if the answer is "yes," and a score of 0 if the answer is "no." The maximum possible score in the questionnaire is 28. Participants with scores above the cut-off score ($\geq$17) were classified as having good musical abilities, while those with scores below the cut-off score (<17) were classified as having poor musical abilities. All study participants in groups I and II received scores of $\geq$ 17, while those in group III received scores of < 17.

After the preliminary inclusion tests, all the participants (group 1, group 2, and group 3) of the study underwent a battery of auditory tests targeting two binaural processing abilities: Binaural integration (DST and VASI) and binaural interaction (ITD and ILD). While DST, ITD, and ILD were conducted using the psychoacoustic toolbox in MATLAB version 2019b software (Mathworks, Natick, Massachusetts, USA) and the VASI test (Nisha & Kumar, 2017) was administered using Paradigm Player (Paradigm Stimulus, 2016).

2.3. Tests for binaural interaction

2.3.1. ITD and ILD thresholds

The ITD and ILD tests were carried out by introducing three consecutive noise bursts (250 ms, stereo, 16 bit, 44100 sampling frequency with 10 ms onset and offset cosine ramps, at 65 dB SPL) played sequentially to both ears in each run. Two were standard stimuli which produced a mid-line percept, and the variable stimuli had embedded lateralization cues of ITD (delay in one channel) and ILD (higher amplitude to the one ear).

The psychoacoustic toolbox (Soranzo and Grassi, 2014) in MATLAB software was used to control the stimulus presentation and the acquisition of responses for the ITD and ILD tests. Both the tests were performed using Sennheiser HD 280 headphones (Denmark, Germany) coupled to a professional sound card MOTU MICROBOOK II (Cambridge, Massachusetts, USA). The participants were asked to select the number on the keyboard that corresponded to the interval in which the variant stimulus (interval in which the sound leads or is heard louder in the right ear) was presented. A three-down one up procedure was used. The variable stimuli in the initial run started at 20 dB higher in right ear, whereas for the ITD it was delayed by 30 ms in the left ear. As a result of nature of the delay and level differences introduced in the variable stimuli, they always produced a lateralization to the right ear. As the test progressed, the step size of the variable stimuli in the successive runs changed: the ITD test used a factor size of 2, while the ILD test used a step size of 2 dB. The testing ended at 10 reversals, and an average of the last four reversals were taken, converging at 79.4% of the psychometric function (Levitt, 1971).

2.4. Tests for binaural integration

2.4.1. VASI test

The VASI test used is adapted from the study by Nisha and Kumar (2017). Following familiarisation with the stimuli and task, the VASI test was conducted. The stimuli were delivered at 65 dB SPL using the paradigm experimental builder program (calibrated using SLM - B&K, 2270). The VASI test involved presentation of virtual stimuli randomly from 8 locations (8 locations*10 repetitions = 80 times).

Sound lab 3D version 6.7.3 (sound module of slab 3D, NASA Ames research institute, USA) was used to create the stimulus for the illusionary effect of virtual auditory space. These stimuli were designed to contain 250 ms white band noise which were convolved with the default head related transfer function from the slab 3D database, corresponding to eight different virtual perceptions across 360° acoustic space. Each virtual location is separated from the other by an angle of 45° as shown in Fig. 1. The virtual stimuli were loaded into paradigm player (Paradigm Stimulus, 2016) and presented randomly using a professional soundcard Motu Microbook II (Cambridge, Massachusetts, USA) which was connected to a laptop. The stimuli from the sound card were routed to Sennheiser HD 280 headphones (Sennheiser GmbH & Co. Wedenmark, Germany) and played at 65 dB SPL. The participants were informed to respond to the stimuli by clicking the arrow/mouse pointer which was located on the user interface corresponding to the virtual location. Termination of the test was done after the competition of 80 trials. The VASI scores were stored as an output Excel file and were subjected to spatial accuracy analysis using a confusion matrix.

2.4.2. DST

Two different verbal stimuli are presented simultaneously to the two ears of individuals in a procedure known as dichotic listening. The material used was dichotic consonant-vowel, each list consisting of 30 standardized pairs of syllables/pa/,/ta/,/ka/,/ba/,/da/&/ga/. The test material was developed by Yathiraj (1999).

The stimuli were created using natural speech samples from a female speaker, with each pair of stimuli having onsets that were 2.5 ms apart and vowel amplitudes that were 2.5 dB apart. Each of the 30 potential pairs of two separate CV syllables were presented in a set, where the presentation of the pairs was randomized within the set. None of the CV pair was played more than three times in one ear. Within the 30-trial set, the interval between the onsets of succeeding pairs was 6 s. Using a laptop and headphones

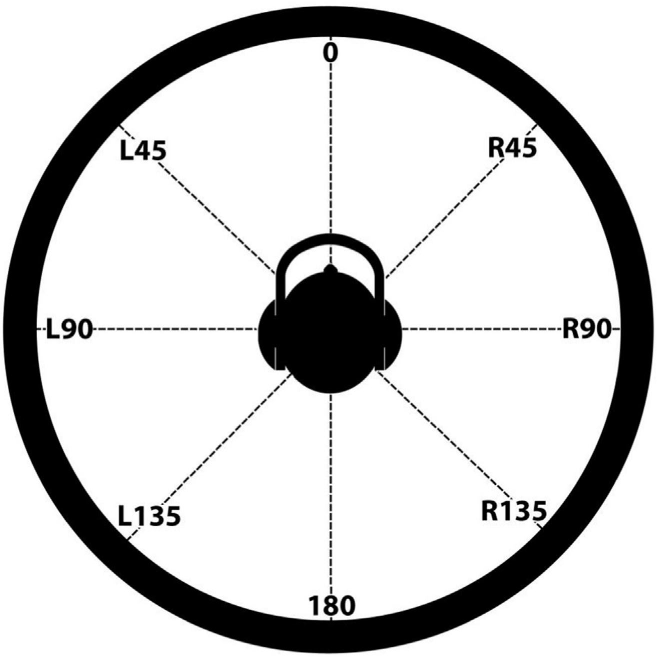

Fig. 1. The graphical user interface used for stimulus presentation and response aquisition in VASI test.

(Seinhesser HD 280, Sennheiser GmbH & Co. Wedenmark, Germany), the stimulus was given binaurally at 65 dB SPL. The headphone was calibrated to give the appropriate output using a sound level meter (Bruel and Kjaer 2270, Hottinger Brüel & Kjær A/S. Nærum, Denmark) in a 6 cc coupler. The participants were asked to repeat the syllables heard in both ears. The single correct scores for the right ear, single correct scores for the left ear, and double correct scores of all participants were recorded.

2.5. Statistical analyses

The collected data were subjected to check for normality in distribution using Shapiro-Wilks's test using IBM Statistical Package Social Sciences (SPSS v26) (IBM Corp., Armonk, NY). Following this, MANOVA was conducted for the comparison of parametric data among the three groups, i.e., vocalists, instrumentalists, and non-musicians while non-parametric Kruskal-Wallis (H) test was employed for data which was not normally distributed. Post-hoc comparisons were done using the Bonferroni test. Whenever significant effects were seen, corresponding effect size values were reported.

3. Results

The descriptive statistics including the mean, and standard deviation for all the tests (ITD, ILD, VASI and DST) across the three groups is shown in Fig. 2, suggestive of better binaural integration and interaction in the musician groups (instrumentalists and vocalists) compared to the non-musicians. Shapiro-Wilk's test showed normality in data distribution ($p > 0.05$) across the three groups for tests of ILD, VASI, and DST while the data concerning ITD did not adhere to normality ($p < 0.05$).

MANOVA test on parametric data revealed main effect of the group for ILD test [$F(2, 83) = 3.40$, $p = 0.04$, $\eta_p^2 = 0.08$], VASI [$F(2, 83) = 14.14$, $p < 0.001$, $\eta_p^2 = 0.25$] and DST [$F(2, 83) = 3.24$, $p = 0.04$, $\eta_p^2 = 0.07$], as reflected in Table 1. The post-hoc Bonferroni pairwise comparisons shown in Table 2, indicated that vocalists and instrumentalists had significantly lower/better ILD ($p = 0.03$) compared to non-musicians, while the ILD thresholds of the former two groups ($p = 0.28$) were similar. For the test of DST, while both musicians groups (instrumentalists and vocalists) scored significantly higher scores than non-musicians, the vocalists had significantly higher dichotic syllable identification scores compared to instrumentalists ($p = 0.04$). For VASI, the instrumentalists had significantly higher spatial identification scores compared to the vocalists ($p = 0.01$), who in turn demonstrated significantly better spatial accuracy scores than non-musicians ($p = 0.04$). The non-parametric Kruskal-Wallis (H) test for ITD established a significant main effect of groups ($|H| = 12.16$, $p = 0.01$, $\varepsilon_R^2 = 0.14$). The results of post hoc Dunn Bonferroni test revealed that instrumentalists and vocalists had significantly lower/better ITD thresholds than non-musicians ($p < 0.01$), with the performance being similar between the two musician groups ($p > 0.05$).

A MANOVA for location-wise group difference in VASI tests showed the main effect of the group as shown in Table 3. Fig. 3 depicts the results of the Bonferroni test for location-wise comparisons between groups, which showed that when the stimulus was presented in the back plane with the virtual sound source on the right or left (R135, & L135), instrumentalists had significantly higher spatial accuracy scores ($p < 0.01$) compared to vocalists. There was no significant difference seen in spatial accuracy scores between the instrumentalists and vocalists in the other virtual locations ($p > 0.05$), although both the former groups had the advantage in all spatial locations over the non-musicians.

4. Discussion

The study was carried out to explore differences in binaural integration and interaction between instrumentalists, vocalists, and non-musicians. We were specifically interested in finding out the differences in the binaural processing within musicians with different background of training including those with instrumental training and vocal training, based on the rationale of hemispheric differences in linguistic and non-linguistic processing in musicians (instrumentalists, vocalists) and non-musicians. We used a psychoacoustic test battery which included measures of binaural integration and binaural interaction. These tests included ITD and ILD for binaural interaction, and DST, and VASI for binaural integration respectively. In support of our hypothesis, statistically significant differences (Table 2) were observed among the three groups of participants (non-musicians, vocalists, instrumentalists), with the musical groups (vocalists, instrumentalists) demonstrating significant advantages over the non-musicians in both binaural integration and interaction tasks, indicative of refined psychoacoustical competence in them in the binaural tasks. Professional musicians, after years of intensive training, have usually improved functional auditory processing as compared to non-musicians, in addition to other structural alterations (Başkent et al., 2018; Bidelman et al., 2011; Kishon-Rabin et al., 2001; Zatorre et al., 2007).

In support to the literature on binaural processing (Johnson et al., 2021; Luiz et al., 2021; Parbery-Clark et al., 2013), the findings of the current study also showed an binaural processing advantage in both the musical groups (vocalists and instrumentalists), who outperformed their non-musician conterparts (Fig. 2a and b). The finding that musicians (instumentalists and vocalists) had a significant advantage over non-musicians in the binaural tasks, can be attributed to whole brain activity in musicians (Krzyżak, 2021). Whole brain activity refines binaural processing due to the inter-hemispheric interaction in the tasks for the musician groups (Krzyżak, 2021), which are otherwise not so appreciable in non-musicians. Although evidence in current study

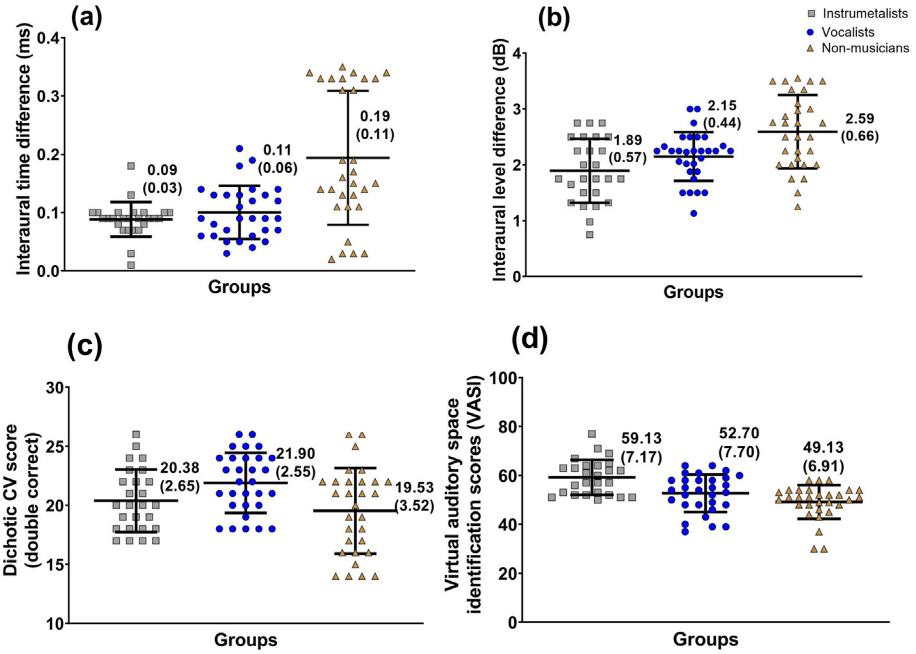

Fig. 2. Comparison of performance of the three groups on (a) ITD, (b) ILD, (c) DCV, and (d) VASI tests. Descriptive statistics showing mean depicted by long line at center along with ± one standard deviation (SD: error bars) are given. Individual symbols represent the scores of each participant.

Table 1
Age, gender and musical experience of the participants.

Variables	Instrumentalists (n = 26)	Vocalists (n = 30)	Non-musicians (n = 30)
Age	17.73 ± 2.83	19.30 ± 2.47	18.20 ± 3.02
Gender (m/f)	13 males, 13 females	16 males, 14 females	17 males, 13 females
Starting age of musical activity (y)	15.31 ± 1.3	16.25 ± 0.8	Not trained
Current level of musical engagement (hours/week)	11.31 ± 10.3	13.53 ± 9.0	3.07 ± 3.6

Table 2
Results of post-hoc Bonferroni test for parametric measures (ILD, VASI & DST) and Dunn Bonferroni test for non-parametric measure (ITD). *p* values for each pairwise comparisons is given.

Tests	Pairwise comparisons		
	Instrumentalists and vocalists	Vocalists and non-musicians	Instrumentalists and non-musicians
Interaural Time difference (ITD)	0.09	0.01	0.01
Interaural level difference (ILD)	0.51	0.03	0.02
Virtual Auditory space identification (VASI, overall accuracy)	0.01	0.01	0.001
Dichotic syllable (DCS)	0.04	0.01	0.02

Table 3
Results of ANOVA for the main effect of group across virtual locations in VASI test. Results of Bonferroni comparisons for significant pairs is given in Fig. 3.

Virtual location	Main effect of the group *F* (2, 83) =	*p* (significance)	Effect size partial eta square (η_p^2)
R45	6.81	0.01	0.14
R90	1.13	0.33	0.03
R135	26.12	<0.001	0.39
180	3.78	0.03	0.08
L135	12.38	<0.001	0.23
L90	0.94	0.39	0.02
L45	14.95	<0.001	0.27
0	1.78	0.18	0.04

show better binaural processing in musicians compared to non-musicians, there is still a possibility of musicians with predisposed better ability of binaural processing (musical sleepers) can not be denied and must be considered as an extraneous variable.

Following a detailed analysis of the data, it was found that for binaural interaction tests (ITD & ILD), both instrumentalists and vocalists out-performed non-musicians (Table 2). However, vocalists and instrumentalists had comparable performance outcomes

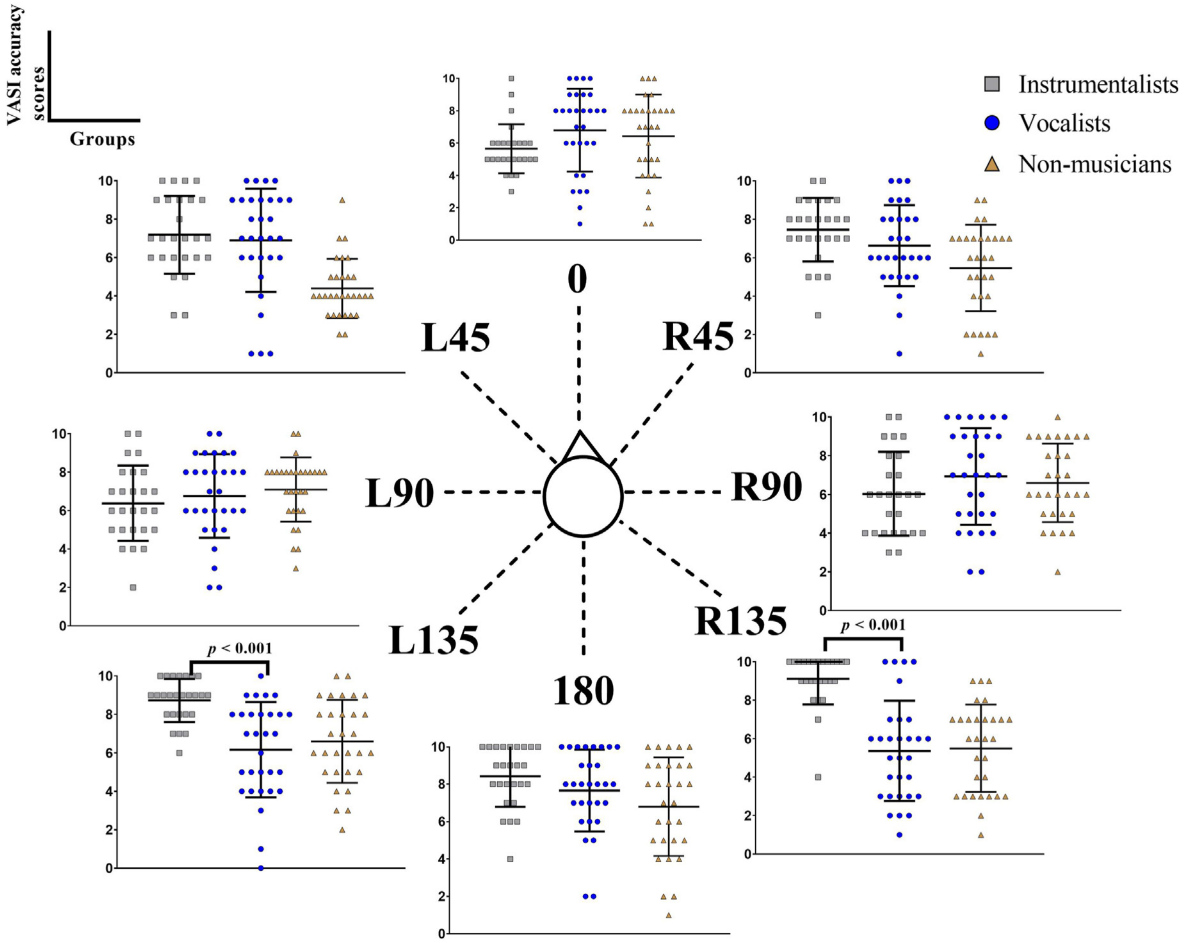

Fig. 3. Comparison of performance of the three groups at each virtual location in VASI test. Descriptive statistics showing mean depicted by long line at center along with ± one standard deviation (SD: error bars) are shown. Individual symbols represent the scores of each participant at each virtual location. Results of Bonferroni comparisons for significant pairs is also highligted.

on ITD and ILD, with neither groups having a clear advantage over the other group. On the binaural integration tests (VASI & DST), the findings from VASI test revealed that instrumentalists performed better than vocalists and non-musicians. Meanwhile, the DST test results revealed that vocalists performed better than instrumentalists as well as non-musicians (Table 2, Fig. 2). For the stimulus having phonetic information as in DST, vocalists were observed to outperform instrumentalists and non-musicians (Table 2, Fig. 2). But when tasks are not phonetically loaded (eg., WBN in test of VASI), instrumentalists performed better than vocalists. This finding can be related to fine-grained harmonic pitch perception in instrumentalists compared to vocalists (Nikjeh et al., 2009). Harmonic pitch perception is the ability to perceive the F_0 of any sound even when it is not physically present. This attribute is inherent to the auditory system and can be enhanced through the practice of manipulating subtle frequency variations with musical instruments. Consequently, individuals with such training may exhibit improved binaural integration skills when processing non-linguistically laden stimuli, surpassing the abilities of vocalists. The latter group (vocalists) have an additional task of monitoring the lyrics (phonetic information) of the song along with maintaining the pitch of their voice giving them an advantage (over instrumentalists) in phonetically loaded tasks such as DST. We assume that for the F_0 perception is more important in instrumentalists than vocalists, whereas, spatial and linguistically loaded information processing is better in vocalists than instrumentalists.

It should be noted that when the virtual sound source was presented in the back (R135 and L135) plane in either the right or left hemifield (Fig. 3), instrumentalists reported significantly higher spatial accuracy scores compared to vocalists. The superiority of instrumentalists over vocalists for sounds coming from the back plane whenever the source is in the right or left side can be attributed to how their brain interacts with the sound. According to Celma-Miralles and Toro (2019) “spatial location of sounds interacts with the organization of rhythmic events and music expertise”. The cues for brain to disambiguate the sound sources in the back plane are dependent on the high frequency cues (Blauert, 1997). The brain analyses the spectral content of the signal at the eardrum and compares that with a template of learned spectral filtering patterns (priori spectrum) to establish the signal location in the back plane (Brimijoin and Akeroyd, 2016). The training of musical instruments appears to have fine-tuned the high frequency representations in the instrumentalists (who might have inherently learned the processing of higher harmonics that eminate from their instruments in comparison to vocalists who depend on vocal apparatus that has restricted range).

4.1. Implications

There is a differential advantage of musical background on binaural processing skills, which further lends support to the use of musical training in individuals/children with binaural processing deficits. Introducing musical training to an individual can enhance the binaural processing skills. This may not be limited to a type of musical training as both vocalists and instrumentalists outperform non-musicians. This will be useful, especially for the population with auditory processing deficits (APD) and spatial processing defecits, where musical training can be approached as a rehabilitative strategy. Further brain plasticity following musical training on different backgrounds can help researchers establish new treatment procedures for functional or structural deficits, which can impair binaural processing.

4.2. Future directions

There is a need to carry out a larger-scale study to find out the efficacy of different backgrounds and genres of musical training and their effect on the perception of pure tone, speech, and speech in competing signals. There should be investigations with an even more diverse population including musicians with a different instrumental experience like string -, wind -, brass-, and percussion instrumentalists. There is a necessity for studies to be carried out to evaluate F_0 perception differences among musicians of different musical backgrounds. The study was done on a smaller population with less diversity in the musical experience. Hence there is a need to verify the findings of the study in a larger sample size, accounting for factors such as variations in musical backgrounds, duration of experience, and age of start of musical training. Future studies using brain imaging experiments are warranted in the direction of exploring the differences in neural generators for spatial processing that vary as a function of type of musical training.

5. Conclusions

The study examined differential effects of musical backgrounds (instrumentalists, vocalists) on binaural integration and interaction. The disparities amongst musicians with different musical backgrounds was readily seen on VASI and DST tests. While, instrumentalists considerably outscored vocalists on the VASI test, vocalists performed better on DST tests. In general both the musical groups consistently performing better than non-musicians in all tests (VASI, DST, ITD & ILD). The results of this study highlight the benefits of musical training on binaural integration and interaction skills, regardless of participants' backgrounds. The findings indicate that musicians, regardless of their specific musical backgrounds, demonstrate enhanced abilities in distinguishing similar sounds between two ears (which vary on the duration, frequency and intensity domain) and their integration at higher centers.

Declaration of competing interest

There is no conflict of interest to disclose. This is a non-funded research.

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