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Relationship between differential auditory sensitivity and central auditory processing among musicians and nonmusicians

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Abstract

Background Music is the art of combining vocals or instruments to form the beauty of expression. Perception of the sounds includes two types of processing: bottom-up and top-down. Earlier studies have reported that musicians outperformed nonmusicians in the discrimination of frequency, intensity, duration, temporal processing tasks, and working memory. The present study compared musicians' and nonmusicians' differential sensitivity and auditory processing abilities in children and younger adults.

Methods A total of 120 participants in the age range of 9–15 years and 18–25 years were recruited for the study and were further divided into four groups: children musicians, children nonmusicians, young adult musicians, young adult nonmusicians group A, B, C, D, respectively. Each group consisted of 30 participants. Further, all the participants were assessed with Differential sensitivity tests such as DLI, DLF, DDT, GDT, and Dichotic CV.

Results The study revealed a high statistical difference in the DLI, DLF, DDT, GDT, and DCV, indicating that children who learned music had better scores than those who did not. A similar trend was observed for younger adults, wherein musicians scored better than nonmusicians on differential sensitivity and auditory processing abilities.

Conclusion It was observed that younger adults (musicians and nonmusicians) showed no difference in Dichotic CV, which shows that the maturation and auditory ability of the younger adults are stabilized. Hence, the present study infers that intensive musical training influences superior performance in auditory perceptual tasks.

Keywords Musicians, Nonmusicians, Differential sensitivity, Auditory processing

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Background

Music which gives color to sounds combines vocals or instruments to form the beauty of expression. The music incorporates frequency (high or low notes of the sound), intensity (loudness), duration (time length of the note played), and timbre (quality or color of the sound), and musicians can distinguish these unique characteristics through their consecutive years of music experience [1]. Perception of sounds includes two types of processing: bottom-up and top-down (extending from the frontal to auditory cortex). Bottom-up (peripheral sensory information) processing focuses on enhancing the incoming acoustic signal. In contrast, top-down processing (language, cognition, metacognitive functions), a higher-level process, utilizes prior knowledge to extract meaning from acoustic signals more efficiently. Studies have demonstrated that temporal regions are engaged with bottom-up processing and frontal areas with top-down processing [1].

The Dichotic CV test is of top-down modulation, and the difference limen is of peripheral level. It has been hypothesized that musicians have enhanced auditory processing and cognitive skills. Supportive to the hypothesis, studies have demonstrated that musical training enhances top-down auditory processing and induces brain plasticity even for beginners [1]. Studies have shown that musicians possess enhanced temporal perception skills across and within-channel gap detection tests (GDT) and better speech perception in noise abilities, indicating improved Medial Olivocochlear Bundle functioning [2–4]. Rammsayer [5] suggested that musicians showed superior temporal acuity than nonmusicians for auditory fusion, rhythm perception, and temporal tasks. Unlike nonmusicians, earlier studies have consistently hypothesized that musicians have better frequency discrimination [6]. Peter and Stuart [7] reported that the difference limen sensitivity for frequency (DLF) was smaller in musicians than in nonmusicians at both interstimulus intervals (ISI) of 0.5 or 2.0 s in duration, but in DLIs, i.e., difference limen for intensity were smaller for musicians only when inter stimulus interval ISI = 0.5 s and did not differ when ISI = 2.0 s.

Recent research has supported that individuals with musical abilities have inherent auditory skills without formal training that influences the neural encoding of speech, as indicated through music relayed neuroplasticity using music-evoked frequency-following responses (FFRs) and event-related potentials (ERPs) [8]. Musicians had lower auditory modality of discrimination contrary to nonmusicians; when the standard duration was increased, both musicians and nonmusicians had improved discrimination [9]. Studies have shown that musicians outperform dichotic chords and directed-recall conditions than nonmusicians [10]. A comparative study between musicians and nonmusicians showed that vocal musicians had demonstrated superior performance in duration discrimination using pure tone, pulse train duration discrimination, gap detection threshold, and differential limen of frequency tests [11].

Jain et al. [12] reported that children musicians had enhanced frequency, intensity, temporal resolution abilities, and working memory. However, studies on adult musicians and nonmusicians have revealed structural brain differences, plausibly due to training-induced neural plasticity [13]. Neuroplastic changes were noticed in the auditory cortex and the auditory brainstem (consisting of lower-level sensory regions) in musicians [1]. These studies reveal that musical training induces anatomical and physiological changes in the auditory system and brain [14]. Hence, there is a need for a detailed comparative investigation of differential sensitivity and auditory processing abilities in musicians and nonmusicians. Also, there is a need to compare and correlate the musicians' and nonmusicians' differential sensitivity and auditory processing abilities within and between the age groups. The study aims to correlate the auditory processing abilities (gap detection and Dichotic CV test) and differential sensitivity (difference limen for frequency (DLF), difference limen for intensity (DLI), and duration discrimination (DD) task) among children and young adult groups (musicians and nonmusicians). Furthermore, the study intends to compare differential sensitivity of frequency, intensity, duration, and auditory processing ability between musicians and nonmusicians of children and young adult groups.

Method

Participants

A total of 120 participants in the age range of 9–15 years and 18–25 years were recruited for the study and were further divided into four groups: children musicians, children nonmusicians, young adult musicians, young adult nonmusicians into group CM, CNM, YAM, YANM, respectively, based on their age and their musical ability were assessed using a questionnaire on music perception abilities [15]. The advertisement flyers were circulated in and around Tiruchirappalli District of Tamil Nadu State, India, for participation in the study based on which participants volunteered. In the musician group, the musical trainees played one or more musical instruments (including violin, guitar, piano, and veena). Each group consisted of 30 participants. The musician's group were formal music practitioners for at least 1 h a day. Further, the participants were ruled out when there was a significant family history, intake of ototoxic drugs, neurological symptoms, congenital or acquired outer ear disorder, (or) middle ear disorder, and exposure to loud sounds. All participants were required to fill out the consent form before testing, which specifies the participants' willingness to participate in the study, and no participants were paid; their participation in the study was voluntary. In the current study, all of the testing procedures were accomplished using a noninvasive technique and adhered to the conditions of the institutional ethical approval committee. The test procedures were clearly explained to the participants before testing.

Procedure

All the participants were evaluated with pure tone audiometry (Inventis Padova, Italy), Immittance evaluation (Inventis Padova, Italy), and Transient Evoked otoacoustic emission (HIS, Miami, FL). A calibrated dual-channel Inventis Piano (Inventis Padova, Italy) with TDH39 headphone and a B-71 Bone vibrator was used to test the hearing through air conduction (AC) and bone conduction (BC) modes. The AC thresholds were measured following frequencies 250 to 8000 Hz, and BC was carried from 250 to 4000 Hz in octave frequencies. A criterion of 15 dB HL pure tone average of 500, 1000, −2000, and 4000 Hz was considered to rule out peripheral hearing loss. Immittance evaluation was assessed using Inventis Clarinet (Inventis Padova, Italy). This middle ear analyzer included Tympanometry and acoustic reflex test in a 226 Hz probe in 500, 1000, 2000, and 4000 Hz frequencies. Transient Evoked otoacoustic emission was assessed through the Intelligent Hearing Systems (IHS, Miami, FL) and recorded in both ears. All the participants had AC and BC pure tone thresholds to their octave frequencies, less than or equal to 15 dB HL in both ears.

The air conduction (AC) and bone conduction (BC) thresholds were estimated using the Modified Hughson and Westlake procedure (Carhart et al., 1959). The participants had type "A" tympanogram (Margolis & Heller, 1987) with normal Ipsi-lateral and contralateral acoustic reflex thresholds within 100 dB HL at 0.5 Hz, 1 kHz, and 2 kHz acoustic reflex and the presence of transient evoked otoacoustic emission in both ears. The tests were all assessed in the sound-treated room within permissible limits ANSI S3.1–1999 (R 2008).

The central auditory processing abilities include an assessment of dichotic processing. The Dichotic CV test, a binaural integration [16], was assessed on the participants using a recorded version of stimuli from an HP laptop routed through the calibrated audiometer. The stimuli were played through the TDH-39 supra-aural headphones in a sound-treated room. The stimuli consisted of 30 pairs of voiced CV syllables (/ba/ka/da/ga/ta/pa/). The stimulus was delivered at a level of 50 dB SL (ref. speech reception threshold) with an interstimulus interval of 6 s and a 0 ms lag between two ears. Three practices were allowed for each person, and the participants were asked to write down their responses in the response sheet.

The psychophysical abilities include an assessment of Differential sensitivity tests like differential limen for intensity (DLI), differential limen for frequency (DLF), duration discrimination (DD) tasks, and gap detection test (GDT), and they were considered for the study. In DLI, the participants were asked to identify the loudest sound. The DLI was delivered through the maximum likelihood procedure (MLP) implemented by MATLAB software in the laptop, and the stimulus was given through the TDH-39 supra-aural headphones. There were three blocks, each consisting of 30 trails with the 3AFC method. The stimuli used were 1-kHz and 250-ms pure tones. The onset and offset of the tones were gated with two 10 ms raised cosine ramps. In DLF, the participants were asked to identify the highest pitch among the three blocks for each block consisting of 30 trials with the 3AFC method carried out using maximum likelihood procedure (MLP) implemented by MATLAB software, which was in laptop, and the stimulus was given through TDH-39 supra-aural headphones. The stimuli used were 250-ms long pure tone obtained. The onset and offset of tones were gated on and off with two 10 ms raised cosine ramps. In DD tasks, the participants were asked to identify the longest noise, and DDT was administered using white noise. The noise had raised cosine onset and offset gates of 10 ms. The DD tasks were performed using a maximum likelihood procedure implemented by MATLAB software, delivered through TDH-39 supra-aural headphones. In GDT, subjects were presented with three blocks of signal in which one block had a variable gap, and the subjects were instructed to identify the gaps. All these tests had 30 trials per block, and 3 blocks with the 3AFC method were used to carry out the testing through MLP, implemented by MATLAB software.

Results

The data were tabulated and analyzed to test the study's hypothesis using Statistical Package for Social Science (SPSS) v21. The data were assessed for descriptive statistics, where the mean and standard deviation (SD) for differential sensitivity (DLF, DLI, DDT, and GDT) and Dichotic CV for both groups of participants were computed and depicted in Table 1. The data were subjected to the test of normality using the Shapiro–Wilks test of normality. It revealed that data were distributed normally, and further parametric inferential statistics were done to test the hypothesis. The data were initially compared between the ears for the measures of DLF, DLI, DDT, DCV, and GDT; a paired sample *t*-test revealed ($p < 0.05$), indicating a highly significant difference between the ear with a better performance in the right ear compared to left ear in all the four groups and hence, for further analysis, the data were assessed separately for each ear and depicted in Table 2.

The performance of children and adults was compared between musicians and nonmusicians using a paired sample *t*-test, which revealed a high significant difference ($p < 0.001$) between the groups, indicating musicians were able to perform better than nonmusicians in both the children and adult group for the

Table 1 Mean and standard deviation (SD) for differential sensitivity (DLF, DLI, DDT, and GDT) and Dichotic CV for both the groups of participants

			DLF	DLI	DDT	GDT	Dichotic CV (SCS)	Dichotic CV (DCS)
Children Mean (SD)	**Musician**	**Right**	74.40 (7.94)	6.29 (1.42)	37.05 (4.51)	2.58 (0.34)	24.30 (1.82)	20.73 (1.43)
		Left	86.98 (17.89)	6.46 (1.04)	38.94 (4.06)	2.74 (0.38)	23.16 (1.85)	
	Nonmusician	**Right**	128.88 (7.62)	9.99 (0.87)	67.23 (8.05)	3.44 (0.37)	16.80 (2.32)	12.40 (2.90)
		Left	128.89 (29.41)	9.75 (1.26)	65.34 (7.03)	3.58 (0.37)	14.46 (2.87)	
Young adult Mean (SD)	**Musician**	**Right**	8.48 (4.05)	2.74 (0.56)	23.81 (3.98)	2.00 (0.44)	26.83 (1.39)	24.70 (1.46)
		Left	10.46 (3.82)	3.30 (0.38)	25.47 (3.42)	2.09 (0.44)	25.46 (1.63)	
	Nonmusician	**Right**	66.37 (9.74)	6.13 (1.22)	52.33 (8.44)	2.61 (0.73)	24.90 (0.88)	18.40 (1.58)
		Left	61.23 (8.64)	6.68 (1.02)	53.04 (6.21)	2.83 (0.58)	22.43 (2.41)	

Note: *DLF* difference limen for frequency, *DLI* difference limen for intensity, *DDT* duration discrimination thresholds, *GDT* gap detection thresholds, *SCS* single correct scores, *DCS double correct s*cores

Table 2 Comparison between the ears for the measure of differential sensitivity (DLF, DLI, DDT, and GDT) and Dichotic CV for both the group of participants

Right ear vs left ear	Musicians				Nonmusicians			
	Children		Young adult		Children		Young adult	
	$t_{(58)}$	*p*-value	$t_{(58)}$	*p*-value	$t_{(58)}$	*p*-value	$t_{(58)}$	*p*-value
DLF	−3.63	0.01	−0.002	0.999	−4.28	0.000	−5.99	0.000
DLI	−0.59	0.556	1.00	0.325	−6.66	0.000	−2.74	0.010
DDT	−7.93	0.000	0.98	0.332	−4.61	0.000	−0.94	0.354
GDT	−7.39	0.000	−7.25	0.000	−2.24	0.033	−3.69	0.001
Dichotic CV (SCS)	4.852	0.000	5.72	0.000	8.80	0.000	4.91	0.000

Note: *DLF* difference limen for frequency, *DLI* difference limen for intensity, *DDT* duration discrimination thresholds, *GDT* gap detection thresholds, *SCS* single correct scores

measures of differential sensitivity and auditory processing abilities and it is depicted in Fig. 1.

The performance of DLF, DLI, DDT, GDT, and Dichotic CV outcomes between the adult musicians, and children musicians were compared using paired sample *t*-test revealed ($p < 0.001$) a high significant difference between the adults and children, indicating adults have better performance in all the test when compared to children. However, the same trend was observed in a nonmusician group, with adults performing better than children; the data is depicted in Table 3. When the performance of the differential sensitivity and auditory processing abilities is correlated within all four groups, the Pearson correlation revealed no significant correlation between the measure of differential sensitivity and auditory processing abilities. However, among children musicians, the gap detection thresholds alone had a moderate negative correlation with the auditory processing abilities as indicated by a high significant difference between the GDT and Dichotic CV single correct scores. The data is depicted in Table 4.

The study's results indicated that music learning ability in children and adults provided better temporal coding and auditory processing abilities than individuals who did not have music knowledge.

Discussion

The results of the current study showed that there were significant differences in the performance of musicians versus nonmusicians among children and young adult groups, where children and young adult musicians performed better compared to children and young adult nonmusicians, respectively, in differential sensitivity and auditory processing abilities (gap detection and Dichotic CV test). The considerable dissimilarity between musicians and nonmusicians suggests that musical training hugely affects higher-order mechanisms.

Relative results were observed while comparing the performance between children and young adults, where the young adult group showed a better performance when compared to children among both musicians and nonmusicians. However, while correlating the differential

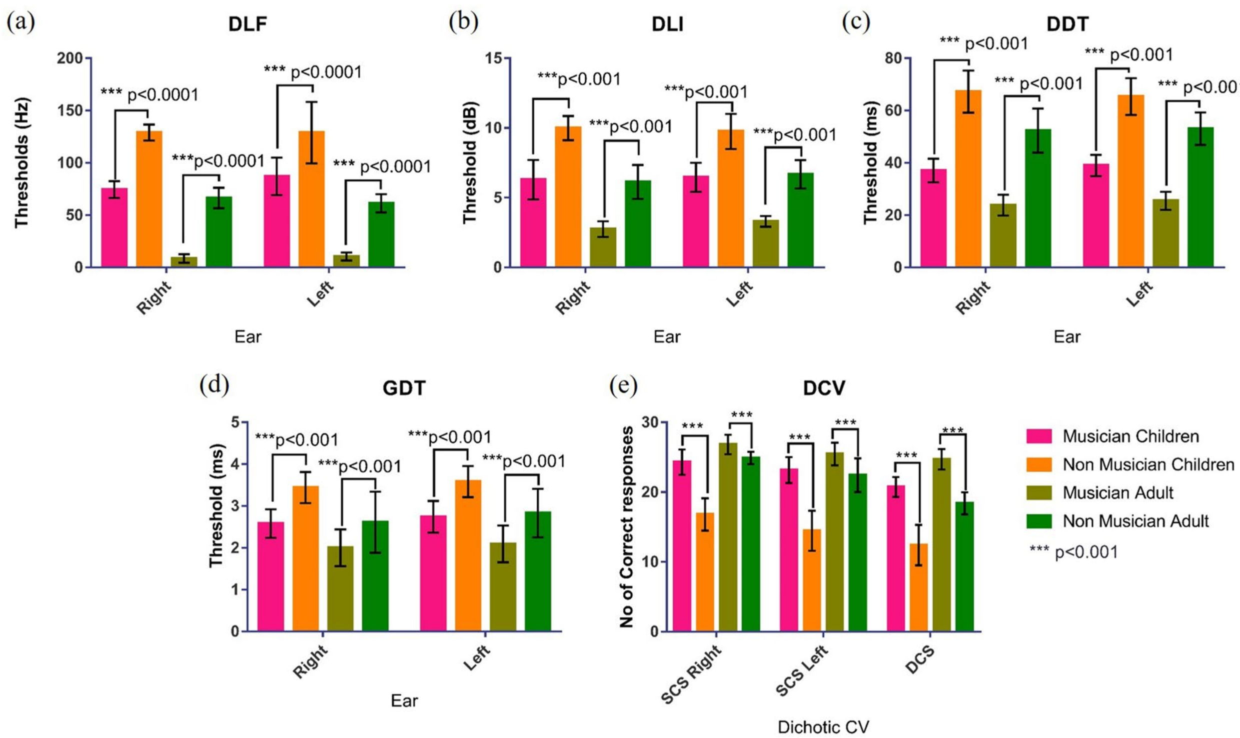

Fig. 1 Comparison of differential sensitivity and auditory processing abilities among four groups. Note: difference limen for frequency (**a**), difference limen for intensity (**b**), duration discrimination threshold (**c**), gap detection threshold (**d**), and Dichotic CV test (**e**)

Table 3 Comparison between the children and adult musicians for the measure of differential sensitivity (DLF, DLI, DDT, and GDT) and Dichotic CV

Children vs young adult			DLF	DLI	DDT	GDT	Dichotic CV (SCS)
Musicians	**Right ear**	$t_{(58)}$	40.46**	12.64**	12.04**	5.63**	−6.05**
	Left ear	$t_{(58)}$	22.90**	15.48**	13.86**	6.07**	−5.09**
Nonmusicians	**Right ear**	$t_{(58)}$	27.66**	14.06**	1.06**	5.56**	−17.83**
	Left ear	$t_{(58)}$	20.77**	10.34**	7.17**	5.84**	−11.62**

Note: *DLF* difference limen for frequency, *DLI* difference limen for intensity, *DDT* duration discrimination thresholds, *GDT* gap detection thresholds, *SCS* single correct scores

** *p*-value < 0.001

sensitivity with Dichotic CV, results revealed no correlation between the measures except the measure of GDT, which had a moderate negative correlation with Dichotic CV indicating little/no effect of music learning abilities between musicians and nonmusicians in children and young adults. In addition, it was observed that younger adults (musicians and nonmusicians) showed no difference in Dichotic CV in correlation with differential sensitivity, which shows that the maturation and auditory ability of the younger adults are stabilized.

The outcomes of the current study are in accordance with earlier studies where children with musical abilities performed better in frequency discrimination [7, 12, 17], intensity discrimination [7, 12], temporal processing skills [12, 18], and duration discrimination [12] concerning auditory stimuli. The study also supports the findings of Kumar et al. [12], where adult musicians performed better than nonmusicians on duration discrimination using pure tone, pulse train duration discrimination, gap detection threshold, and differential frequency limen for frequency.

The present study results are in conjunction with the previous study in which Nelson and Wilson [10] observed no differences among the groups in the Dichotic-CV test.

Table 4 Correlation between the measure of differential sensitivity (DLF, DLI, DDT, and GDT) and Dichotic CV among children and adult musician

Pearson correlation $r_{(29)}$			Right ear				Left ear			
			DLF	DLI	DDT	GDT	DLF	DLI	DDT	GDT
Children	**Dichotic CV (SCS)**	**Right ear**	−0.05	−0.07	−0.08	**−0.67***	0.03	−0.11	−0.05	**−0.67***
	Dichotic CV (SCS)	**Left ear**	0.08	0.03	−0.07	**−0.67***	0.25	−0.14	−0.06	**−0.64***
	Dichotic CV (DCS)		−0.03	−0.23	0.03	−0.19	0.17	−0.10	−0.06	−0.19
Young adult	**Dichotic CV (SCS)**	**Right ear**	−0.25	0.05	−0.30	0.11	−0.21	−0.17	−0.15	0.03
	Dichotic CV (SCS)	**Left ear**	−0.35	0.01	−0.06	0.01	−0.37	−0.12	−0.02	−0.11
	Dichotic CV (DCS)		−0.37	−0.12	−0.50	0.20	−0.31	−0.05	−0.45	−0.07

Note: *DLF* difference limen for frequency, *DLI* difference limen for intensity, *DDT* duration discrimination thresholds, *GDT* gap detection thresholds, *SCS* single correct scores, *DCS* double correct scores

* p-value < 0.001

The current research infers that intensive exposure to auditory learning will result in the shaping of auditory perceptual abilities; in addition, it conveys that musical training, irrespective of age, increases the unprompted attention to the sound perceived and the capacity to distinguish.

Summary and conclusion

The present study strengthens and validates the findings of earlier studies that compared and correlated the differential sensitivity (frequency, intensity, duration) and auditory processing abilities (GDT and Dichotic CV test) among young adult and children musicians versus nonmusicians, where children and young adult musicians perform better than nonmusicians. Hence, the study implies that musical learning affects superior performance on various acoustic tasks. The study also revealed that young adult musicians performed better when compared to children musicians, which infers that young adults possess enhanced functional plasticity reflecting their years of musical experience, thus emphasizing that extensive musical training improves a person's ability to attend to refined grains of auditory sound.

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Authors' contributions
SA, PNS, and PSE were involved in the study design, acquisition of data, drafting of the manuscript, and interpretation of the results; DN was involved in the study design, supervision, drafting the manuscript, and critical revision of the manuscript and interpretation of the results; UR* and KK were involved in the study design, supervision, critical revision of the manuscript, and statistical analysis.

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Availability of data and materials
Not applicable.

Declarations

Ethics approval and consent to participate
In the current study, all of the testing procedures were accomplished using a noninvasive technique and adhered to the conditions of the institutional ethical approval committee. Under the Helsinki Declaration for noninvasive procedures on human data, the Holy Cross College Ethical Committee approved the study IEC No: HCC/ERB/EC/PB-03/2023–24 dated 26/06/2023. The test procedures were clearly explained to the participants before testing. Informed written consent was taken prior to commencing the data collection from all the participants (adult group) and participant's parent (children group – as all the children are below 16 years).

Consent to participate
Written informed consent was taken prior to commencing the data collection.

Consent for publication
Not applicable.

Competing interests
The authors declare that they have no competing interests.

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