ISSN: 2083-389X,
eISSN: 2084-3127

J Hear Sci, 2021; 11(2): 37–43
DOI: 10.17430/JHS.2021.11.2.4

FREQUENCY FOLLOWING RESPONSES IN VOCALISTS, VIOLINISTS, AND NON-MUSICIANS TO CARNATIC MUSICAL STIMULI

Contributions:
A Study design/planning
B Data collection/entry
C Data analysis/statistics
D Data interpretation
E Preparation of manuscript
F Literature analysis/search
G Funds collection

Prajna Bhat J[1,A-F], Rajalakshmi K[2,A,D-F]

[1] Audiology, Samvaad Institute of Speech and Hearing, India
[2] Department of Audiology, All India Institute of Speech and Hearing, Mysuru, Karnataka, India

Corresponding author: Prajna Bhat J, Audiology, Samvaad Institute of Speech and Hearing, Bengaluru 560024, India; email: prajnabhat13@gmail.com

Abstract

Introduction: The current study investigates pitch coding among vocalists, violinists, and non-musicians to Carnatic musical stimuli.

Material and methods: Three groups of participants were included in the study: 10 trained Carnatic vocalists, 10 violinists,and 10 non-musicians. Their ages ranged from 18 to 45 years. Two types of stimuli were given: three notes of a Carnatic raga (S R2 G3) sung by a trained vocalist and three notes of a Carnatic raga (S R2 G3) played on violin by a trained violinist. Frequency following responses (FFRs) were recorded binaurally at 80 dBSPL for both stimuli using Neuroscan equipment.

Results: Grand average responses of all participants were generated. To assess a participant's pitch tracking to the Carnatic music stimuli, stimulus-to-response correlation, pitch strength, and pitch error were calculated. Vocalists and violinists had better stimulus-to-response correlation and pitch strength values with lower pitch error values than non-musicians for both vocal and violin stimuli. Within both the vocalist and violinist groups, superior performance was noticed for the vocal stimulus compared to the violin stimulus. No such preference was evident among non-musicians.

Conclusions: Classical music training dependent plasticity can be demonstrated at brainstem level itself. This holds true for both vocal and violin music, a finding not reported previously. Further a link between musical training and the FFR response can be more strongly demonstrated for vocalists than for violinists.

Key words: frequency following response • musicians • pitch coding

SŁUCHOWE POTENCJAŁY WYWOŁANE FFR U WOKALISTÓW, SKRZYPKÓW I NIEMUZYKÓW W ODPOWIEDZI NA BODŹCE W POSTACI MUZYKI KARNATYCKIEJ

Streszczenie

Wprowadzenie: Niniejsze badanie dotyczy kodowania wysokości dźwięku wśród wokalistów, skrzypków i osób niebędących muzykami w odpowiedzi na bodźce w postaci muzyki karnatyckiej.

Materiał i metody: W badaniu uczestniczyły trzy grupy: 10 wyszkolonych wokalistów karnatyckich, 10 skrzypków i 10 niemuzyków. Ich wiek wahał się od 18 do 45 lat. Podawano im dwa rodzaje bodźców: trzy nuty ragi karnatyckiej (S R2 G3), śpiewane przez wyszkolonego wokalistę, i trzy nuty rago karnatyckiej, granej na skrzypcach przez wyszkolonego skrzypka. Dla obu bodźców potencjały wywołane podążające za częstotliwością (FFR) były rejestrowane obuusznie dla 80 dB SPL, korzystając z urządzenia Neuroscan.

Wyniki: Obliczono średnią z odpowiedzi wszystkich uczestników badania. W celu oceny śledzenia przez uczestników częstotliwości w odpowiedzi na bodziec w postaci muzyki karnatyckiej obliczono korelację bodźca z odpowiedzią, siłę wysokości dźwięku i błąd wysokości dźwięku. W odpowiedzi na dwa rodzaje bodźców u wokalistów i skrzypków występowała wyższa korelacja bodźca z odpowiedzią i wyższe wartości częstotliwości oraz niższe wartości błędu częstotliwości niż u niemuzyków. Zarówno w grupie wokalistów, jak i w grupie skrzypków zanotowano lepsze wyniki odpowiedzi na bodziec wokalny w porównaniu do odpowiedzi na bodziec zagrany na skrzypcach. Wśród niemuzyków nie stwierdzono takiej zależności.

Wnioski: Plastyczność mózgu będącą wynikiem klasycznego wykształcenia muzycznego można wykazać już na poziomie pnia mózgu. Dotyczy to zarówno muzyki wokalnej, jak i skrzypcowej, co jest odkryciem nigdy wcześniej nieraportowanym. Ponadto związek między wykształceniem muzycznym a odpowiedziami wywołanymi FFR jest silniejszy u wokalistów niż u skrzypków.

Słowa kluczowe: potencjały wywołane podążające za częstotliwością FFR • muzycy • kodowanie wysokości dźwięku

Introduction

Musicians develop mastery over their voice or their instrument of choice through years of sensory-motor training, often beginning in early childhood. During training, they learn to attend to the fine-grained acoustics of musical sounds which include pitch, timing, and timbre. The frequency following response (FFR) offers a reliable and objective method to study neural pitch encoding at the brainstem level by preserving the spectral and temporal aspects of the original stimulus such as fundamental frequency. This helps in comparing the frequency components of the stimulus to that of the FFR [1]. Studies on FFRs evoked by music have included stimuli such as a bowed cello note [2,3], a five-note musical melody [4], consonant and dissonant two-note intervals synthesized from an electric piano [5], and tone complexes [6].

Musicians can be further grouped either on the basis of their training styles (Western, Indian, Classical, Jazz etc.) or their preferred mode of rendition (vocal, instrumental). The vocal vs instrumental dichotomy is the most common reported in the literature. In the FFRs of musicians, there is ample evidence that the F0 of the original acoustic waveform is faithfully reproduced, a finding that could reflect the neuroplasticity-induced changes brought about by training. The F0 of musical notes varies between different musical instruments and vocal music. The FFR is known to be a reliable measure of neural encoding of F0 of the source signal, and so it might help in delineating the relative importance of factors contributing to the superior ability of musicians in their perception of pitch and how it is neurally encoded.

Some of the factors that need further exploring are musical style and training method for playing a particular musical instrument or vocal music. If training affects the pitch perception of musical notes, then vocalists may be more tuned to the pitch of voices whereas instrumentalists to the notes of instruments. While the neural encoding of F0 of musicians has been studied, little is known regarding the effect of stimulus factors like timbre (of musical notes) and the acoustics of instrumental music on the neural encoding of F0. Furthermore, the same musical note produced by a natural voice or an instrument varies in itsF0-harmonic combinations [7]. This is relevant to the present study, as the perception of musical notes by vocalists and instrumentalists may in part be related to the distinct F0-harmonic relationships in the acoustics of a sounded note. For perception of the pitch of musical notes, vocalists rely on their larynx to produce different pitches, while instrumentalists produce non-verbal sounds from instruments such as violin, veena, guitar, etc. Both employ a different skill set and require different levels of training for mastery [7,8]. While information is available on FFR results using western musical stimuli, limited information is available on FFR results among musicians tested using classical Indian music (vocal and instrumental).

Classical Indian music has two main branches: Carnatic and Hindustani. The Carnatic music branch is practised in the southern regions of India. Its elements include Shruthi, Swara, Raga, and Tala, which form the basis for the composition of musical note sequences. Musical rendition in the Carnatic style involves a small ensemble of musicians, consisting of a vocalist, a melodic accompaniment (usually a violin), a rhythm accompaniment (often an mridangam), and a tambura, which acts as a drone throughout the performance. The vocalist is the lead performer as well as the de facto conductor, so that instrumentalists follow them. Devi and Kumar [9] recorded FFRs to Carnatic transient music stimuli of 127 ms (a /sa-ga/ transition). They found a significant relationship to the musical aptitude of non-musicians to FFR parameters such as pitch strength (PS), pitch error (PE), and stimulus-to-response correlation (SRC). Non-musicians with musical aptitude produced higher values of PS and SRC, and lower values for PE, than those without musical aptitude.

Enhanced neural encoding among musicians needs to be assessed using longer duration musical stimuli, e.g. 'raaga' in Indian classical music, as it can then capture the dynamic aspects of their pitch perception abilities. Furthermore, whether the encoding varies between the notes of an instrument and the notes of a vocalist is not evident in the literature. Therefore, it would be interesting to study how musicians' training history affects their neural processing at the brainstem level. The current study is a preliminary attempt to add data in this area.

The aim of the study was to investigate neural pitch coding in the brainstem using FFR parameters derived from vocalists, violinists, and non-musicians using Carnatic vocal and violin music stimuli and to compare the results.

Material and methods

Participants

A total of 30 participants in the age range 18–45 years were recruited for this study. Purposive sampling was used to select the participants. The participants were divided into three groups. The first group consisted of 10 professionally trained Carnatic vocalists (mean = 24.2 years, SD = 4.0). The second group consisted of 10 professionally trained Carnatic violinists (mean = 22.8 years, SD = 5.9). Both the vocalists and violinists had a minimum of 5 years of experience in their area of expertise. The mean age of formal musical training initiation was 8.5 years (SD = 4.5 years). The musical background of the vocalists and violinists is summarized in Table 1. The third group of participants consisted of 10 non-musicians (mean = 24.8 years, SD = 3.9) who had no prior training in Carnatic vocal or violin music. All participants had bilateral normal hearing sensitivity (pure tone air and bone conduction thresholds within 15 dBHL at octave frequencies from 0.25 to 8 kHz and 0.25 to 4 kHz respectively) and no history of ontological or neurological problems and no noise exposure. All participants had speech identification scores of 90% and above. Absence of any middle ear problems at the time of FFR recording was ascertained with impedance testing. Bilateral A-type tympanograms with the presence of ipsilateral and contralateral reflexes were obtained in all participants. Informed written consent was taken from all participants prior to conducting the study in accordance with the ethical guidelines of the institute where the participants were tested. An informal questionnaire was used to document the education, lifestyle, musical history, and medical history of the participants.

Procedure

The study was carried out in two phases. Phase I related to Carnatic music stimulus preparation while Phase II involved FFR recording using the musical stimuli.

Phase I: Two types of stimulus were recorded, vocal and instrumental (violin). To record the Carnatic vocal stimulus, a female vocalist trained in Carnatic music sang the first three notes of the mo:hanara:ga in Arohana (ascending scale) using the vowel /a/ (Alapana) as the base pitch. The mo:hana raga is a composition using only five notes (S R2 G3 P D2) of a total of seven notes. It is a symmetric pentatonic scale. The recording was carried out in a sound-treated room using a sensitive microphone and a MOTU Microbook II external sound card connected to a laptop. Adobe Audition software was used for the recording.

Table 1. Musical background of the vocalists and violinists

Musicians	Chronological age (years)	Age of music training initiation (years)	Musical proficiency
Vocalist 1	22	12	Senior
Vocalist 2	22	12	Senior
Vocalist 3	22	4	Senior
Vocalist 4	22	6	Senior
Vocalist 5	22	3	Senior
Vocalist 6	28	21	Senior
Vocalist 7	30	8	Senior
Vocalist 8	30	5	Senior
Vocalist 9	26	17	Junior
Vocalist 10	18	11	Junior
Violinist 1	23	7	Junior
Violinist 2	24	8	Junior
Violinist 3	22	5	Junior
Violinist 4	19	9	Junior
Violinist 5	18	6	Senior
Violinist 6	19	10	Junior
Violinist 7	18	4	Junior
Violinist 8	22	10	Junior
Violinist 9	25	4	Junior
Violinist 10	38	8	Senior

Carnatic music has 3 levels of proficiency: Junior, Senior, and Vidhwat. Proficiency exams are conducted by the Karnataka Secondary Education Board

The stimulus was recorded at a sampling rate of 44.1 kHz. Multiple stimulus tokens were recorded. The duration of the token was 393 ms. A total of 5 tokens were shortlisted based on quality. These 5 tokens were subjected to a goodness test by asking 5 experienced vocalists to rate these tokens on a 5-point scale based on their naturalness and quality. The highest rated token was selected for the purpose of the study. The pitch contour varied from 241 to 311 Hz across the three notes.

For the instrumental stimulus, a trained violinist listened to the vocal stimulus recorded earlier. They were then asked to play the violin in such a way that it matched the vocal stimulus as closely as possible with respect to pitch and tempo. Using the same procedure as that for the vocal, 5 tokens of the first three notes (S R2 G3) were extracted and subjected to a goodness test. The highest rated token was selected for the purpose of the study. The pitch contour varied from 241 to 310 Hz across the three notes. The duration of the token was 393 ms. Both the vocal and violin stimuli were matched with respect to pitch contour and duration.

Phase II: Recording of FFR to music stimuli. All participants were educated about the test procedure. They were instructed to sit in a reclining chair and minimize their body and head movements as much as possible. They watched a muted video with subtitles. The FFR was recorded using Neuroscan equipment (Compumedics, USA). Responses were recorded separately to the vocal and instrumental Carnatic stimuli for an 80 dBSPL sound presented binaurally using electrically shielded insert earphones to electrodes placed on the nape of the neck (C7, inverting), Cz (vertex, non-inverting), and low forehead (ground). The electrode impedances were less than 5k ohms for all participants. FFR recordings involved a total of 2000 sweeps for each of the two stimuli (vocal and violin) in alternating polarity to reduce stimulus artifacts.

The stimuli were presented through the sound module of Stim 2 (Compumedics, USA). The interstimulus duration (calculated from offset to onset) was 135 ms and the stimulus presentations (vocal and violin) were randomized across participants. Continuous electrophysiological data were collected at a sampling rate of 20 kHz using a Synamps 2 amplifier. The collected data for Carnatic vocal and violin stimuli was subjected to online data pre-processing which consisted of artifact rejection (±35 μV), filtering (80–1800 Hz), epoching, and averaging using Curry 7. Grand average responses of all participants in the two groups were generated separately for Carnatic vocal and violin stimuli.

Data analysis

The data were analysed using Brainstem toolbox, version 2013 in Matlab (version 7.3). To assess the participants' pitch tracking to the Carnatic vocal and violin music stimuli, three parameters were considered: stimulus-to-response correlation (SRC), pitch strength (PS), and pitch error (PE). See reference [9] for details of the procedure. SRC measures the similarity between stimulus and response F0 contours using Pearson's *r*-value. The analysis uses a short-time running autocorrelation technique wherein the response is chopped into 40-ms chunks and is successively time-shifted with a delayed ("lagged") version of itself (in 1-ms steps); a Pearson's *r* is calculated at each 1-ms interval. PS refers to the strength of relationship (0 to 1). PE measures the average pitch deviation of the response contour (in Hz) from the stimulus contour.

Statistical analysis

Data were analyzed using the Statistical Package for the Social Sciences (SPSS) v.20 (IBM, Armonk, NY, USA). Descriptive statistics, including mean and SD, were calculated for musicians and non-musicians for the two stimuli (vocal vs violin) for the three parameters pitch error, pitch strength, and stimulus-to-response correlation. Both within-group and between-group comparisons were carried out.

Results

Comparison of pitch coding between vocalists and non-musicians for vocal and violin stimuli

Figures 1, 2, and 3 represent the means and standard deviations (SD) for vocalists, violinists, and non-musicians for the parameters of pitch strength (PS), pitch error (PE), and stimulus–response correlation (SRC) respectively for vocal and instrumental stimuli. Tests of normality and homogeneity (Levene's test) were carried out prior to the *t*-test.

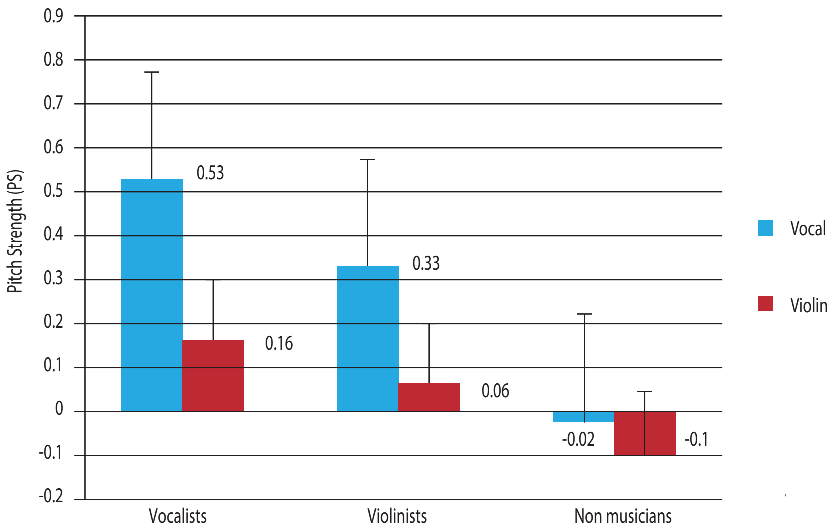

Figure 1. Mean and standard deviation (SD) of pitch strength for vocalists, violinists, and non-musicians for vocal and violin stimuli

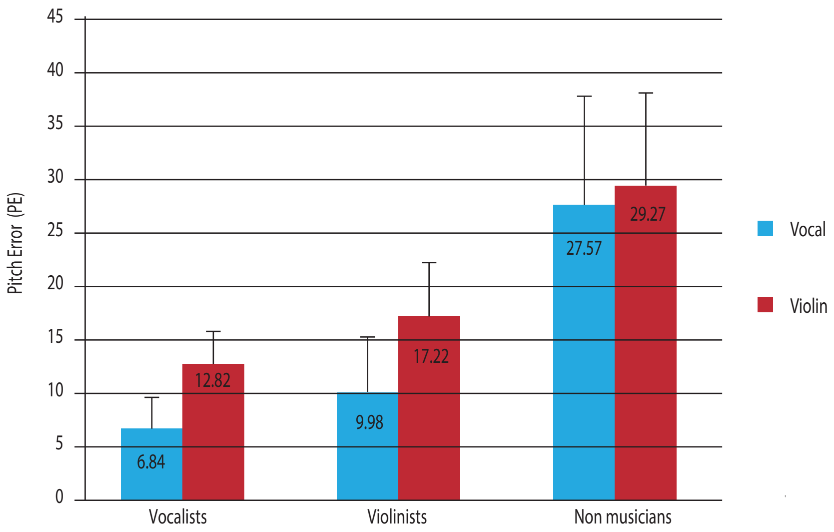

Figure 2. Mean and standard deviation (SD) of pitch error (Hz) for vocalists, violinists, and non-musicians for vocal and violin stimuli

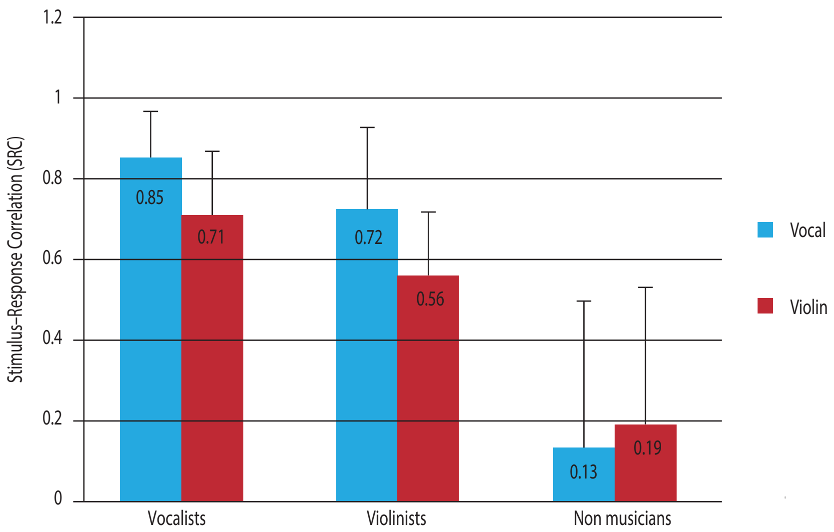

Figure 3. Mean and standard deviation (SD) of stimulus–response correlation for vocalists, violinists, and non-musicians for vocal and violin stimuli

Independent *t*-tests were done to compare the mean PE, PS, and SRC between the two groups for vocal and instrumental stimuli. For the vocal stimulus, a significant difference for PS [$t(18) = 8.43$, $p<0.005$, $\eta_P^2 = 0.89$], PE [$t(18) = -6.20$, $p<0.005$, $\eta_P^2 = 0.81$], and SRC [$t(18) = 5.89$, $p<0.005$, $\eta_P^2 = 0.81$] was observed between the two groups of participants. With the violin stimulus, the results revealed a significant difference for PS [$t(18) = 4.72$ ($p<0.005$, $\eta_P^2= 0.74$], PE [$t(18) = -5.50$, $p<0.005$, $\eta_P^2 = 0.79$], and SRC [$t(18) = 4.33$, $p<0.001$, $\eta_P^2 = 0.71$] between the two groups of participants. Vocalists had superior performance compared to non-musicians for both stimulus types.

Comparison of pitch coding between violinists and non-musicians for vocal and violin stimuli

For the vocal stimulus, a significant difference for PS [$t(18) = 3.95$, $p<0.001$, $\eta_P^2 = 0.68$], PE [$t(18) = -4.83$, $p<0.005$, $\eta_P^2 = 0.75$], and SRC [$t(18) = 4.41$, $p<0.005$, $\eta_P^2 = 0.72$] was observed between the two groups of participants. With the violin stimulus, results revealed a significant difference for PS [$t(18) = 2.74$, $p<0.01$, $\eta_P^2 = 0.54$], PE [$t(18) = -3.70$, $p<0.002$, $\eta_P^2 = 0.65$], and SRC [$t(18) = 3.10$, $p<0.006$, $\eta_P^2 = 0.59$] between the two groups of participants. Violinists had superior performance compared to non-musicians for both stimulus types.

Comparison of pitch coding between vocalists and violinists for vocal and violin stimuli

For the vocal stimulus, a significant difference for PS [$t(18) = 2.28$, $p<0.05$, $\eta_P^2 = 0.47$] was observed, with vocalists performing better than the violinists. No significant difference between the two groups was seen for PE [$t(18) = -1.62$, $p>0.05$, $\eta_P^2 = 0.35$] and SRC [$t(18) = 1.75$, $p>0.05$, $\eta_P^2 = 0.82$]. With the violin stimulus, results revealed a significant difference for PE [$t(18) = -2.31$, $p<0.05$, $\eta_P^2= 0.48$] and SRC [$t(18) = 42.15$, $p<0.05$, $\eta_P^2 =0.45$], with vocalists performing better than the violinists. However, no significant difference was observed for PS [$t(18) = 1.77$, $p>0.05$, $\eta_P^2 = 0.38$].

Comparison of pitch coding in vocalists for vocal and violin stimuli

For vocal stimuli, the mean PS was 0.53 (SD = 0.14), PE was 6.85 (SD = 2.85), and SRC was 0.85 (SD = 0.12). For the violin stimuli, the mean PS was 0.17 (SD = 0.11), PE was 12.83 (SD = 3.13), and SRC was 0.71 (SD = 0.16). A paired *t*-test was used to determine if a statistically significant difference existed within the group for the two stimuli. The results revealed a significant difference for PS [$t(9) = 6.10$, $p<0.005$, $\eta_P^2 = 0.9$], PE [$t(9) = -4.90$, $p<0.001$, $\eta_P^2 = 0.85$], and SRC [$t(9) = 2.70$, $p<0.05$, $\eta_P^2 = 0.67$] for vocal stimulus over violin stimulus.

Comparison of pitch coding in violinists for vocal and violin stimuli

For vocal stimuli, the mean PS was 0.33 (SD = 0.24), PE was 9.98 (SD = 5.40), and SRC was 0.72 (SD = 0.20). For the violin stimulus, the mean PS was 0.07 (SD = 0.14), PE was 17.23 (SD = 5.14), and SRC was 0.56 (SD = 0.15). A paired *t*-test was carried out to determine if a statistically significant difference existed within the group for the two stimuli. The results revealed a significant difference for PS [$t(9) = 3.34$, $p<0.01$, $\eta_P^2 = 0.74$], PE [$t(9) = -4.46$, $p<0.002$, $\eta_P^2 = 0.83$], and SRC [$t(9) = 2.29$, $p<0.05$, $\eta_P^2 = 0.61$] for the vocal stimulus over the violin stimulus.

Comparison of pitch coding in non-musicians for vocal and violin stimuli

For vocal stimuli, the mean PS was –0.03 (SD = 0.16), PE was 27.57 (SD = 10.17), and SRC was 0.13 (SD = 0.37). For the violin stimuli, the mean PS was –0.10 (SD = 0.14), PE was 29.27 (SD = 8.93), and SRC was 0.20 (SD = 0.34). A paired *t*-test was carried out to determine if a statistically significant difference existed within the group for the two stimuli. The results revealed no significant difference for PS [$t(9) = 1.97$, $p>0.05$, $\eta_P^2 = 0.55$], PE [$t(9) = -0.67$, $p>0.05$, $\eta_P^2 = 0.21$], and SRC [$t(9) = -0.61$, $p>0.05$, $\eta_P^2 = 0.21$] for vocal vs violin stimulus.

Discussion

This study sought to investigate brainstem encoding of pitch among vocalists, violinists, and non-musicians using Carnatic vocal and violin music as stimuli. The results revealed that, for both vocal and violin stimuli, mean pitch error was smaller, pitch strength was better, and stimulus to response correlation was higher in musicians (vocalists and violinists) compared to non-musicians. Within the musician group, participants performed better for vocal compared to violin stimuli. However, no such stimuli-specific differences in FFR parameters were observed among the non-musicians.

Comparison of pitch coding between musicians and non-musicians

The results of the current study agree with the literature [10–13] that generally demonstrates that experience-dependent plasticity enables musicians to have robust temporal and spectral brain encoding compared to non-musicians. This work adds to the available data on neuroplasticity of the brainstem in the encoding of pitch. The genre of music selected for the study was Indian Carnatic vocal and violin, which have not been explored before and therefore adds to the body of information on neural encoding at brainstem level among musicians.

Comparison of pitch coding between vocalists and violinists

For the pitch strength parameter, and for both vocal and violin stimuli, vocalists performed better than violinists. For all other parameters, both groups performed similarly (Figure 1). Vocalists undergo intense training to have precise motor control over their vocal folds and the mechanism controlling subglottal pressure. This ability enables them to bring about pitch variations independent of variations in the loudness of their voice. Monitoring their own voice by ear is therefore an essential skill for vocalists [14]. Due to the nature of their training, it can be assumed that our vocalists would find it easier to detect pitch variations in the recorded vocal stimulus compared to violinists. Hence, it is to be expected that vocalists would have better scores for pitch strength in their FFR than violinists when a vocal stimulus was used. Another reason may be that 'mohana' raga used in the current study belongs to a group of ragas needing an advanced skill set and training. In classical Indian music training, vocalists are much more likely to undergo rigorous practice compared to violinists, and this may have contributed to the high pitch-strength values.

Comparison of pitch coding in vocalists for vocal and instrumental stimuli

Our results showed that vocalists performed better in response to vocal stimuli than in response to instrumental stimuli. In the Carnatic tradition, vocalists undergo rigorous training under a teacher in which daily practice of musical rendition is carried out. It is auditory-based learning where the student needs to listen to a sequence of notes rendered by the teacher and then the student imitates until it is perfect. Accurate pitch perception for all the notes in a raga is essential, and so the improvisation must suit the musical emotion/tone and rhythm/pace. It can therefore be theorized that vocalists demonstrate better pitch coding not only at the cortical level but at the brainstem level too. Furthermore, since their practice is restricted to vocal training, this might explain why their performance with vocal stimuli was superior to that with instrumental stimuli. Pitch strength was higher among vocalists and the effect size was also very high, suggesting a high degree of correlation between Carnatic training and the brainstem level encoding of pitch.

Comparison of pitch coding in violinists for vocal and instrumental stimuli

Violinists also performed better in response to a vocal stimulus than in response to an instrumental one. This result was unexpected. If training and practice are considered to be a major factor in FFR responses, then the most robust response for violinists was expected to be a violin stimulus. However, the results of the present study did not show such a tendency. The FFR of violinists was better for a vocal stimulus. This indicates that along with training, physical aspects of the stimuli may also affect the results. For the purpose of the study, a natural stimulus was recorded and it was ensured that the harmonic composition of the stimulus was not altered. Nevertheless, it is possible that, because the violin is a string instrument, the actual method of playing may have involved factors, like string tension, which might have introduced aperiodicity in the complex waveforms. FFR recordings are known to be affected by aperiodicities in the stimulus and this may have contributed to poor pitch strength in the recordings with violin stimuli. At the same time, factors that degrade periodicity in vocal stimuli are minimal, and hence FFR responses to vocal stimuli were better than for violin stimuli among violinists also.

Comparison of pitch coding in non-musicians for vocal and violin stimuli

Our FFR studies of non-musicians did not show any preference towards vocal or violin stimuli. For all three parameters and when using either vocal or violin stimuli, FFR values were poorer among non-musicians than those obtained for musicians. As other studies have clearly shown [2,3], musical experience is the major factor, and in our study the absence of musical training resulted in poorer performance in this group irrespective of the stimulus used. However, the mean scores were better for the vocal stimulus than for the violin stimulus, although the difference failed to reach statistical significance.

Conclusions

This study showed that Carnatic musicians (both vocalists and violinists) have better pitch-tracking ability – higher pitch strength, lower pitch error and better stimulus response correlation – to musical stimuli compared to non-musicians. The results indicate that experience-dependent plasticity can, via the FFR, be demonstrated at the brainstem level. This holds true for both vocal and violin music, a finding not reported previously. Furthermore, the link between musical training and FFR response appears to be stronger for vocalists than for violinists.

Acknowledgements

The authors thank the Director, All India Institute of Speech and Hearing for permission and infrastructure to conduct the study. We also thank all the participants.

Financial disclosure

The authors declare that this study has received no financial support.

Conflict of interest

The authors have no conflict of interest to declare.

Ethics committee approval

Ethical clearance was received from the ethics committee of the All India Institute of Speech and Hearing, Mysuru.

Informed consent

Written informed consent was obtained from all participants.

References

1. Skoe E, Kraus N. Auditory brain stem response to complex sounds: a tutorial. Ear Hear, 2010; 31: 302–24.
2. Musacchia G, Sams M, Skoe E, et al. Musicians have enhanced subcortical auditory and audiovisual processing of speech and music. Proc Natl Acad Sci U S A, 2007;104:15894–8.
3. Musacchia G, Strait D, Kraus N. Relationships between behavior, brainstem and cortical encoding of seen and heard speech in musicians and nonmusicians. Hear Res, 2008; 241: 34–42.
4. Skoe E, Fabian C, Kraus N. The effects of musical training on subcortical processing of a missing fundamental piano melody. Poster, Society for Neuroscience conference, 2009, Chicago, IL.

5. Lee KM, Skoe E, Kraus N, Ashley R. Selective subcortical enhancement of musical intervals in musicians. J Neurosci, 2009; 29(18), 5832–40.
6. Bidelman G, Krishnan K. Neural correlates of consonance, dissonance, and the hierarchy of musical pitch in the human brainstem. J Neurosci, 2009; 29(42): 13165–71.
7. Peretz I. The nature of music from a biological perspective. Cognition, 2006; 100: 1–32.
8. Wolfe J. Speech and music, acoustics and coding, and what music might be 'for'. Proceedings of the 7th International Conference on Music Perception and Cognition, Sydney, Stevens K, et al. (eds.), 2002: 10–13.
9. Devi N, Kumar A. Brainstem encoding of Indian Carnatic music in individuals with and without musical aptitude: a frequency following response study. Intl J Health Sci Res, 2015; 5(8): 487–95.
10. Krishnan A, Swaminathan J, Gandour JT. Experience-dependent enhancement of linguistic pitch representation in the brainstem is not specific to a speech context. J Cog Neurosci, 2009; 2: 1092–105.
11. Kraus N, Chandrasekaran B. Music training for the development of auditory skills. Nature Rev Neurosci, 2010; 11(8): 599–605.
12. Wong PC, Skoe E, Russo NM, Dees T, Kraus N. Musical experience shapes human brainstem encoding of linguistic pitch patterns. Nature Neurosci, 2007; 10: 420–2.
13. Strait DL, Kraus N, Skoe E, Ashley R. Musical experience and neural efficiency: effects of training on subcortical processing of vocal expressions of emotion. Eur J Neurosci, 2009; 29(3): 661–8.
14. Zatorre RJ, Baum SR. Musical melody and speech intonation: singing a different tune? PLoS Biol, 2012; 10(7): e1001372.