Research Article

Assessment of Distortion Product Otoacoustic Emissions Input-Output Function in Individuals with and without Musical Abilities

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Highlights

- Musicians have superior functioning of the cochlea
- Neuroplastic changes due to musical training increase cochlear sensitivity

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ABSTRACT

Background and Aim: Musical training has shown to bring about superior performance in several auditory and non-auditory tasks compared to those without musical exposure. Distortion product otoacoustic emissions (DPOAE) input-output function can be an indicator of the non-linear functioning of the cochlea. The objective of this study was to evaluate and compare the differences in the slope of DPOAE input-output function in individuals with and without musical abilities.

Methods: Twenty normal-hearing individuals were considered in the age range of 18–25 years. They were divided based on the scores obtained on the questionnaire of musical abilities, as individuals with and without musical abilities. DPOAE input-output function was done for each of the two groups. The slope of the DPOAE input-output function was compared at different frequencies between the groups.

Results: The results of the Mann Whitney test revealed that the slope was significantly steeper at 2000, 3000, 4000 and 6000 Hz in individuals with musical abilities. There was no significant difference in slope at 1000 and 1500 Hz.

Conclusion: The increased steepness of the slope indicates a relatively better functioning of the cochlea in individuals with musical abilities. The enhanced perception of music may induce changes in the cochlea resulting in a better appreciation of music.

Keywords: Hearing; cochlea; music

Introduction

Music is a form of art, and it plays an essential role in human culture. There is growing evidence that learning music has more general effects on brain plasticity. It is well accepted in the literature that trained musicians have better auditory sensitivity and musical skills compared to non-musicians and untrained musicians [1, 2]. Musical training would help an individual to perceive better the attributes of pitch, loudness, timbre [3]. Bidelman et al. [4] reported sharper tuning curves in musicians than non-musicians using psychophysical tuning curves. Thus, suggesting that their pervasive auditory benefits may be facilitated by physiological mechanisms as early as the cochlea. Micheyl et al. [5] showed a more significant amplitude reduction in evoked otoacoustic emissions with contralateral noise in musicians than non-musicians. It indicates a more significant activity of the medial olivocochlear bundle in musicians than in non-musicians.

An abundance of research evidence suggests that musicians over-perform non-musicians on various tasks, ranging from basic psycho acoustical skills to speech perception in noise [6, 7]. Musicians perform superiorly than non-musicians on a variety of other non-auditory skills such as information processing speed, intelligence, memory [8], problem-solving tasks [9], higher-level cognitive functions [10]. Individuals who had undergone formal music training appears to have an enhancement in processing not only in music but also in linguistic and non-linguistic cognitive processing [10, 11]. Musical training has improved cognitive abilities like a digit span and reading complex words [12].

There are also structural and functional changes of neuroplastic processes as an effect of musical training [13-15]. Professional musicians have fine-tuning of aural skills, which is achieved by ear training obtained during musical training [16], and were able to detect rhythm deviation better than non-musicians [17]. Improved performance in a variety of auditory and cognitive skills such as auditory attention, auditory stream segregation, processing of prosody, and linguistic features in the speech was found as a result of long term musical practice. Otoacoustic emissions provide an index of cochlear function and are linked to outer hair cell health [18]. Distortion product otoacoustic emissions (DPOAE) are dependent on the presentation level of the tones and an input/output (I/O) function that can be obtained by keeping the stimulus frequency and frequency ratio constant. The input-output function slope obtained for different input levels is directly reliant on cochlear health and therefore gives a picture of the supra-threshold non-linear characteristics of the cochlea. The growth of DPOAE with intensity measured through I/O function provides an indirect evidence for cochlear non-linearity as measured in laboratory animals with peak of the travelling wave [19]. This evidence is similar to the psychophysical data of compression in humans [20-22].

Previous studies have established a relationship between DPOAE I/O function and psychoacoustical tests such as loudness scaling and temporal masking curves [23]. This suggests that DPOAE I/O function can be an objective metric for the perceptual compression phenomena. In impaired ears, the slope of the I/O function was steeper [24]. Some studies have also found a correlation between DPOAE threshold estimated using the I/O function and audiometric hearing thresholds [25]. The musicians are reported to have higher functional abilities in various forms like language, speech, memory, speech in noise, and other cognitive activities [9, 26-29]. A simple questionnaire "Questionnaire on Music Perception Ability" [27] can be used as one of the tools to segregate individuals with and without musical skills.

The DPOAE slope is the estimate of increase in DPOAE amplitude with increase in intensity of the stimulus. The slope of the DPOAE I/O function is a clear indicator of cochlear compression. Therefore, input-output function is a valuable measure of assessing cochlear functioning. The relation between these two measures becomes stronger depending on the frequency of the signal [22] and when the repeated estimates are combined in a multivariate analysis. However, there is a shortage of literature regarding the effect of music on fine-tuning at the cochlear level in individuals with musical abilities. They would listen to more music compared to individuals without musical skills. Thus, the present study attempts to evaluate and compare the differences in the slope of DPOAE input-output function at different frequencies (1000, 1500, 2000, 3000, 4000, and 6000 Hz) in individuals with and without musical ability.

Methods

Participants

Twenty participants who are in the age range of 18 to 25 years were recruited for the study. Based on the scores obtained on the "Questionnaire of musical abilities" which is a validated tool to assess musical abilities [27], the two groups were formed with ten participants in each group. The questionnaire had 25 questions with categories such as pitch awareness, pitch discrimination, timbre identification, melody recognition, and rhythm perception. The participants had to answer "Yes" (scored as one) or "No" (scored as zero) for all the 25 questions. Individuals who scored higher than 15 were assigned to Group I (individuals with musical abilities), and those with less than 15 were assigned to group II (individuals without musical skills). The mean score for Group 1 and group 2 was 18.3 (SD=1.3) and 10.2 (SD=2.1) respectively. The participants were selected randomly who regularly prefer listening to music. All the participants listened to music at a lower volume and did not hear for very long duration. The participants of Group I listened to music on an average of 2–3 hours/day at low volume. All participants were required to fill the consent form before testing, which specifies the willingness of participants to take part in the study. Individuals who are presented with any of the following were not considered for the study: having a history or presence of middle ear disorders, any neurological dysfunction, any psychological dysfunction, any other conditions like tinnitus if they are smokers or alcoholics if they are under any medications for other ailments if they are using any ear protective devices.

Procedure

A detailed case history was noted from all the participants to rule out any otological symptoms, work experience in a noisy environment. Pure tone audiometry for octave frequencies from 250 to 8000 Hz was carried out by following modified Hughson and Westlake procedure [30] with a dual-channel diagnostic audiometer in a sound-treated room. A criterion of 15 dB HL pure tone average of 500, 1000, 2000, and 4000 Hz was considered to rule out any peripheral hearing loss. Immittance evaluation was done, which included tympanometry and acoustic reflex testing using a 226 Hz probe tone at 500, 1000, 2000, and 4000 Hz using GSI-Tympstar (Grason-Stadler, Eden Prairie, MN) middle ear analyzer to rule out middle ear conditions. Otoacoustic emissions (OAE) measurements were done through a calibrated Otodynamics ILO V6 Echo port system (Otodynamics Ltd., Herts, United Kingdom). DPOAEs were obtained for two tones, f1 and f2 (primaries), their ratio (f2/f1) being 1.22, with intensities of 65 dB SPL and 55 dB SPL (L1 and L2), respectively. Criteria of + 6 dB SNR at three consecutive frequencies were accepted as the presence of OAE. Participants satisfying the selection criteria were included for further evaluations.

The input-output (I/O) function of DPOAE was carried out in a sound-treated room using the calibrated Otodynamics ILO V6 Echo port system. The test was carried out for tones of frequencies 1000, 1500, 2000, 3000, 4000, and 6000 Hz with a ratio of f2/f1 at 1.22, at different intensities. Intensities were set as primary tone stimulus was L1=(0.4xL2)+39 dB SPL, as the L2 decreased in 5 dB steps according to the stimulus paradigm found to be optimal for clinical testing [28, 31, 32]. With the parameters mentioned above, tests were carried out. The procedure consists of two phases; where the first phase was done to check the correct fit by giving a transient stimulus (frequency sweep) and checking the waveform and spectrum. The second phase was measuring the amplitude of DPOAE at different intensity for each frequency. The emissions at each level were plotted automatically by the instrument. An average of three responses was taken for each response. The slope of the I/O function of DPOAE was calculated using the linear trend model. The I/O of DPOAE data was fitted with a linear function for the stimulus range from 65 to 35 dB SPL. Once a linear fit was obtained, the slope was estimated at 2 points of the x coordinate equal with x2=65 dB SPL and x1=35 dB SPL. Given the corresponding points of DPOAE amplitude as y2 and y1, the slope of the fitted linear function is defined as b=(y2–y1)/(x2–x1) [32].

Results

A descriptive statistical analysis was performed for the collected data using SPSS (Version 4) software. The mean DPOAE amplitudes at different intensities were calculated at all the frequencies which were tested. Figure 1 depicts the averaged DPOAE input-output function obtained at all the six frequencies, which were tested in both the groups. The figure clearly shows differences in the slope between the two groups. Based on the DPOAE amplitudes obtained at different intensities, the slope of the DPOAE I/O function was determined. The mean and standard deviation of DPOAE I/O slopes obtained at 1000, 1500, 2000, 3000, 4000, and 6000 Hz was determined. The mean slope obtained across frequencies for both the groups is shown in Figure 2. Figure 2 shows that the slope is higher for those with musical abilities at all the test frequencies.

Shapiro Wilk test of normality showed that the data was not normally distributed ($p<0.05$). Hence, Mann Whitney U tests were done to compare the differences between the two groups in the DPOAE slope at each of the test frequencies separately. The results of Mann Whitney U tests showed that the slope was significantly steeper at 2000 Hz ($p=0.003$), 3000 Hz ($p=0.021$), 4000 Hz ($p=0.001$), and 6000 Hz ($p=0.012$) in individuals

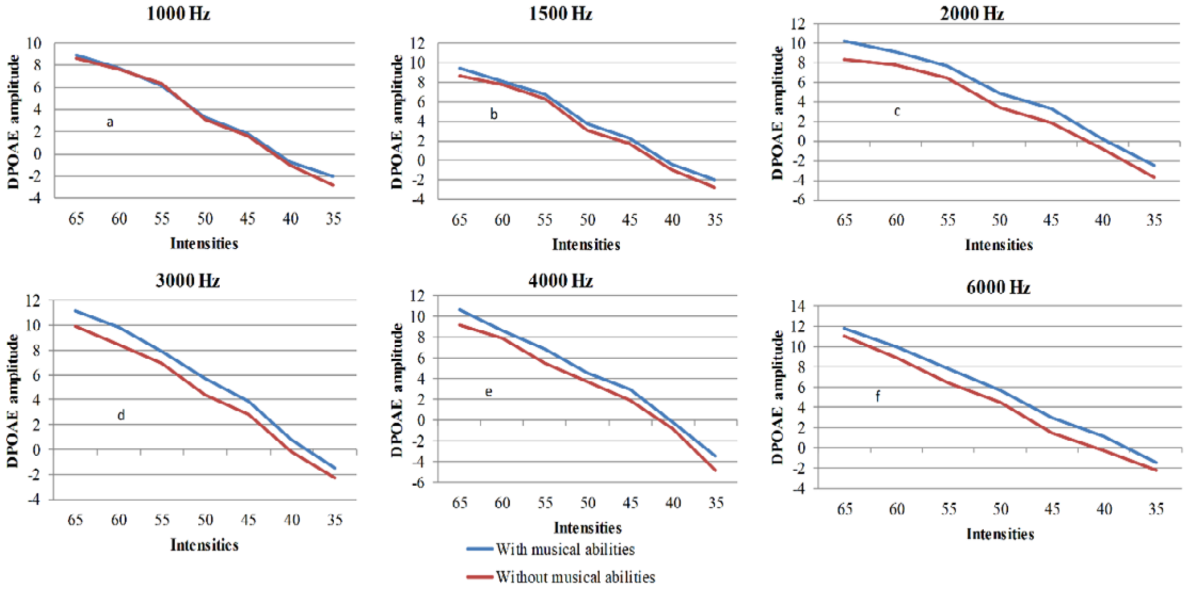

Figure 1. (a-f): average distortion product otoacoustic emissions input-output function obtained at different frequencies in both the groups for frequencies 1000–6000 Hz (a-f): a-1000 Hz, b-1500 Hz, c-2000 Hz, d-3000 Hz, e-4000 Hz, f-6000 Hz. DPOAE; distortion product otoacoustic emissions

with musical abilities. However, there was no significant difference in DPOAE slope at 1000 Hz (p=0.09) and 1500 Hz (p=0.13).

Discussion

The results of the study showed that the DPOAE I/O slope was steeper in individuals with musical abilities at high frequencies. The increased steepness of the slope indicates a relatively better functioning of the cochlea in individuals with musical skills. The enhanced perception of music may induce changes in the cochlea, which assists in a better appreciation of music. Previous studies on musicians have also shown improved performance in auditory and cognitive skills such as auditory attention, auditory stream segregation, processing of prosody, and linguistic feature [28]. Studies have also shown that musicians have improved temporal perception [33], speech perception in the presence of noise [34], and better fine structure abilities [3]. Musical training would help an individual to perceive better the attributes of pitch, loudness, timbre [35]. Bidelman et al. [4] studied forward and simultaneous masked psychophysical tuning curves, and their results showed sharper tuning curves in musicians than non-musicians. Thus, suggesting that music exposure has benefits offered at the cochlear level.

Bidelman et al. [4] measured efferent feedback through otoacoustic emissions. The results of this study indicate that there is an increase in the slope of the DPOAE I/O function as the f2 frequency increases from 1 kHz to 2 kHz. This agrees with the previous studies done by Ab-

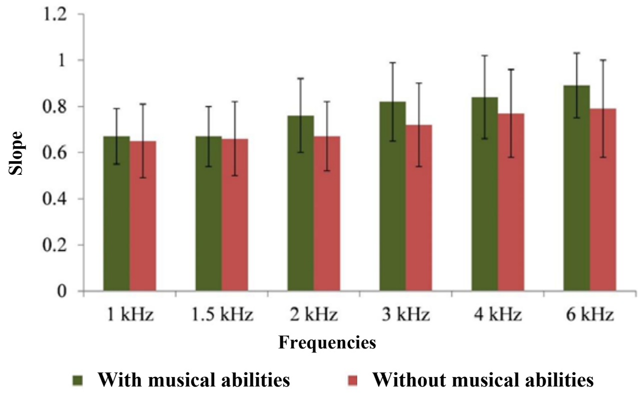

Figure 2. Mean and standard deviation of the slopes across frequencies in both the groups

dala [36] and Probst et al. [37], where the results show a similar trend of increase in the slope with the frequency. It is understood that the medial olivary complex (MOC) is the link in the descending auditory pathway from the cortex involving several centers [38]. It is indicated that the MOC is influenced by the activity of the central auditory nervous system, as there are previous studies that show reduced MOC activity in central anesthesia [39]. Also, it is also well reported that the central auditory system facilitates MOC activity [40]. Thus, it indicates that the increased activity also suggests a heightened activity in the higher-level cortical structures, including the auditory cortex [5]. Thus, the music-induced plasticity is mediated by the top-down process, which is strengthened due to the training.

The individuals with musicial abilities may have subtle auditory abnormlity, not shown in the audiogram, which could have affected the test results. Further studies have to be done on a large population for better generalization. It can be used as a quantitative tool to indicate how musical training has affected the cochlea, and musicians can use it to enhance their skills. It may serve as an essential tool in clinics to document the loss in finer aspects of cochlear functioning in the initial stages of any disorder.

Conclusion

The present study attempted to compare the distortion product otoacoustic emissions (DPOAEs) slope in individuals with and without musical abilities. The results showed that the slope was steeper in individuals with musical abilities, especially at the high frequencies. This suggests a superior functioning of the cochlea in individuals with musical abilities. Thus, musical training might induce subtle changes in the cochlea, which cannot be measured by conventional optoacoustic emissions but can be seen in the distortion product otoacoustic emissions input-output (I/O) function. So the slope of the DPOAE I/O function can be used as a tool to measure the sharpening of cochlear activity in musicians.

Ethical Considerations

Compliance with ethical guidelines

In the present study, all the testing procedures were carried out using non-invasive techniques, adhering to the guidelines of the Ethics Approval Committee of the institute (SH/ERB/PB-102). All the procedures were explained to the participants, and informed consent was taken from all the participants of the study.

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Authors' contributions

KGS: Study design, acquisition of data, interpretation of the results, and drafting the manuscript; MC: Study design, acquisition of data, interpretation of the results, and drafting the manuscript; ND: Study design, drafting the manuscript, interpretation of the results, and critical revision of the manuscript; PP: Study design, drafting the manuscript, statistical analysis, interpretation of the results, and critical revision of the manuscript.

Conflict of interest

The authors report no conflicts of interest. The authors alone are responsible for the content and writing of the paper.

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