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The comprehensive audiological evaluation in young violinists: the medial olivocochlear system, high frequency thresholds, and the auditory figure ground test

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Abstract

Purpose The aim of this study was to examine whether the medial olivocochlear hearing system functions, the high frequency hearing thresholds and speech discrimination in noise performance can guide us in assessing the risk of hearing loss among violinists. It is aimed to investigate possible hearing damage that is not reflected in pure tone hearing thresholds in violinists.
Methods The participants ($n = 50$) who have normal hearing and the ages of 18–30 were included in this study in two groups: violinists and controls who are unrelated to music. High frequency audiometer, auditory figure ground test (AFG) for speech discrimination in noise performance, Distortion Product Otoacoustic Emission (DPOAE) and contralateral suppression on DPOAE for medial olivocochlear system function tests were applied to all participants as well as routine audiological tests.
Results The high frequency hearing thresholds were obtained higher in violinists compared to the controls. In violinists, the AFG test scores and the suppression amount at 1 kHz were lower than the controls. In addition, DPOAE responses at 4–6 kHz were obtained lower in violinists ($p < 0.05$).
Conclusion The reason for high frequency hearing loss, decreased DPOAE response amplitudes, and poor medial olivocochlear function in violinists can be explained by the long-term exposure to high-level noise caused by the violin, one of the closest musical instruments. Routine and comprehensive audiological follow-up is crucial for musicians.

Keywords Violinist · High frequency hearing loss · Medial olivocochlear efferent system · Noise-induced hearing loss

Introduction

The relationship between music and audiological findings has been the issue of constant interest from researchers. While some studies suggest that music training improves speech discrimination in noise performance, improves cortical auditory potentials, [1, 8, 22, 24, 38] it has also been reported that certain levels of exposed noise from the musical instruments negatively affect the hearing performance, lead to tinnitus, etc., especially in rock musicians [5, 7, 19, 26, 30].

Risk factors in the noise-induced hearing loss for musicians are still an area of interest and research. Many studies indicate that there is a risk of noise-induced hearing loss among musicians and this varies with various factors, such as the instrument used, orchestra or solo performance [12, 15, 31]. In a classical orchestra, sound levels range from 80 to 100 dB LpAFmax [14]. A violin is one of the musical instruments located in the position closest to the person and it is stated that the sound level of an acoustic violin is generally between 78 and 95 dB SPL [13]. Exposure to high level auditory stimuli can cause sudden and severe stimulation in the basilar membrane and tectorial membrane and, therefore, damage to the outer hair cells in the organ of corti. During the noise, the blood flow rate decreases, the metabolic deficiency is observed in the stimulation of the sensor

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cells, the neurotransmitters are hyperactive, excitotoxicity is observed in the afferent nerve fibers [29, 36]. At this point, it is a good idea to touch on the otoacoustic emissions (OAEs) associated with the outer hair cells (OHCs). The OAEs are cochlear-induced, mild acoustic energy emissions that can be detected from the outer ear canal. The OAEs from the cochlea are emerged depending on the activity of the outer hair cells [10]. OHCs innervate from the middle part of the superior olivary complex (SOC) via medial olivocochlear (MOC) bundles. These MOC fibers are activated by acoustic stimulation and create an inhibitory effect on OHC mobility. Cochlear micromechanical functions are determined by the contractility of the outer hair cells and the medial olivocochlear efferent regulate them. The MOC fibers help suppress outer hair cell activation against high-intensity auditory stimuli and noise, reducing vibration in the basilar membrane and suppressing outer hair cell's motility, and preventing inner ear damage. The absence of this suppression effect in the presence of noise suggests that the efferent hearing system has a dysfunction and noise-damaged cochlea might exhibit less suppression [9, 16, 20, 21]. This can be measured by otoacoustic emission tests in the presence of contralateral noise. In the physiology of the normal inner ear and efferent hearing system, a decrease in otoacoustic emission responses in the measured ear is expected when the noise stimulus from the contralateral ear is presented. MOC efferent hearing function in violinists has been previously studied by Otsuka et al. In the study evaluating temporary threshold shifts and MOC reflex after 1 h of instrumentation practice, a significant amount of exposure in the left ear has been reported [25]. Although there is a similar starting point in the present study, it is assumed to give different point of view in predicting possible hearing loss in violinists thanks to sample size and the test battery, which includes the speech discrimination test in noise and high frequency hearing thresholds in addition to the MOC function. It is aimed to investigate possible hearing damage that is not reflected in pure tone hearing thresholds in violinists.

In addition, in our current study, unlike the literature, the hearing performance in violinists are evaluated, not musicians in general. In addition, as a contribution to the literature [2, 11, 17], the speech discrimination in noise test and the suppression of otoacoustic emission test are applied together in the same study, which are assumed to be related tests, and high frequency hearing thresholds are also examined. We hypothesized that MOC functions and high frequency hearing thresholds can be applied to assess the risk of hearing loss in violinists, as well as the ability to discriminate the speech in noise with the MOC function, and even high frequency hearing thresholds may be interrelated.

As in some other studies, violinists were selected as participants in this study, because the violin is close to the left ear and contains broadband sounds consisting of many components with different frequencies. Therefore, violinists are exposed to large amounts of noise due to close placement, with potential inter-ear differences compared to other musicians [23, 25, 26, 28]. In addition, our aim is to investigate the differences between the ears in violinists in terms of medial olivocochlear function, speech discrimination performance in noise, and high frequency hearing thresholds.

In conclusion, the primary aim of the study is to investigate whether individuals who play the violin, which is one of the closest instruments to the person, are affected by the medial olivocochlear efferent hearing system, speech discrimination skills in noise and high frequency hearing thresholds, and whether the dysfunctions / deficiencies in these skills may be an early sign of hearing loss in violinists. The secondary aim of the study is to investigate whether there is a relationship between the medial olivocochlear system functions, which are supposed to protect the cochlea from harmful acoustic stimuli, such as noise, and to discriminate the speech in noise and high frequency hearing thresholds.

Method

This study was carried out at Department of Audiology and the University Ethics Committee in accordance with Declaration of Helsinki approved this study with the decision number 507. All subjects in this study approved the informed volunteer consent form.

Participants

The volunteers ($n = 25$) who played violins between the ages of 18–30 and healthy peers who were not related to music ($n = 25$) were included in this study. The mean age of the violinists in the study group (13 of them was female) is 20.40 ± 2.71 years and the mean age of the participants in the control group (15 of them was female) is 20.64 ± 2.55 years.

Inclusion criteria for all participants were; pure tone hearing thresholds at 125–8 kHz are 20 dB HL and better, having a Type A (normal) tympanogram, acoustic reflex thresholds between 80 and 90 dB in normal range, right hand dominance, and for the violinists to play the violin for at least half an hour a day and at least 5 h a week.

Exclusion criteria for all participants were; having an ear infection/operation, having chronic illness associated with hearing, having an additional disability, hearing loss, according to the Tinnitus Handicap Inventory, to have Level 2 and more tinnitus complaints, to have a specific acoustic trauma/explosion history.

Since there is no study hypothesis based on tinnitus, those who have tinnitus mostly Level 1 or who have no tinnitus complaints were included. Only 13 of the violinists had a tinnitus complaint on the left side at Level 1 (according to the Tinnitus Handicap Inventory). There were no participants with tinnitus complaints in the control group.

The participants playing the violin have been playing violin for a mean of 3.76 ± 2.40 years, and it has been reported that they play a mean of 1.66 ± 0.99 h a day and a mean of 11.42 ± 6.07 h a week. Even though they are described as unexperienced violinists, taking into account the age at which they began playing the violin, the period of time they spend playing the violin on a daily, and so forth, this age range has been favored due to the importance of investigating the potential of any auditory problem in the early period. The violinists included in the study had no other activities that cause noise exposure, such as clubbing/festivals/motorcycling/shooting.

Evaluation tools

After the approval of the informed consent form from all participants, a detailed anamnesis and, if necessary, Tinnitus Handicap Inventory were filled out.

The pure tone audiometry in 125–8000 Hz, tympanometry and acoustic reflex thresholds measurements were applied routinely to all participants to comply with the inclusion/exclusion criteria. To the best knowledge of violin players, sound transmission through bone conduction noticeably improves to hearing the violin sound. As a result, in this study, bone conduction hearing thresholds at 500 Hz, 1 kHz, 2 kHz and 4 kHz were obtained from all participants and analyzed. Afterwards, the high frequency audiometry, the Auditory Figure Ground Test (AFG), the Distortion Product Otoacoustic Emission Test (DPOAE) and suppression test on otoacoustic emission were applied.

In the high frequency audiometry test, hearing thresholds of both ear sides at 10, 11.2, 12.5, 14 kHz frequencies were detected with the circumaural headphones in the audiometric booth, where routine audiological tests were performed. According to the aims of the study, the high frequency audiometry was implemented, since the possibility of high frequency hearing thresholds being an early indicator of noise-induced hearing loss in violinists and / or possible hearing loss / dysfunction due to exposure to violin sound was questioned.

In the AFG test, the list consisting of 30 single syllable words in each ear at + 8 dB signals to noise ratio (SNR) was presented at background babble noise and the participant was asked to repeat it. The audio file is presented in a quiet isolated environment with calibrated supra-aural headphones as 50 dB SPL. By giving 1 point to the correct repeated word and 0 point to the wrong repeated word, the total score was obtained for each ear. According on the listener's responses, the greatest score is 30 if he accurately repeats all of the words. The AFG test was conducted to inquire whether the violinists' ability to discriminate speech in noise is affected and whether this is related to medial olivocochlear function or high frequency hearing thresholds.

DPOAEs were measured by Interacoustic Eclipse 15 at 65 dB SPL for f1 and 55 dB SPL for f2 frequencies. The frequency ratio of the two primary tones ($f2/f1$) was fixed at 1.22 dB. DPOAEs at $2f1–f2$ was considered available if the SNR is at least 3 dB between 1 and 6 kHz. Even if the thresholds in the speech frequencies (125–8000 Hz) are normal, DPOAE responses may indicate noise-induced hearing loss and/or dysfunctions caused by exposure to loud sounds. For this, DPOAE measurement was used to evaluate the function of cochlear outer hair cells by taking part in the comprehensive test battery for the purposes of the study.

To evaluate the medial olivocochlear efferent system function, the white noise at 50 dB SPL presented contralateral ear side during DPOAE measurement and SNRs were recorded on each side at each frequency. As we previously touched on the loudness that violinists are exposed to and the violin being an instrument close to the person, we also investigated the medial olivocochlear system functions that are supposed to protect the cochlea from high intensity acoustic stimuli.

Statistics

SPSS version 25 was implemented for the statistical analyses and a p value < 0.05 was considered as clinically relevant. The variables were investigated using visual (histogram and probability plots) and analytical methods (Kolmogorov–Smirnov/Shapiro Wilk's test) to determine whether or not they are normally distributed. Descriptive analyses were presented using mean and standard deviation for normally distributed variables and the p values result from the Independent Samples t test in the groups which demonstrated normal distribution. The scores between the two ears in the same participant were compared with Paired Samples t test in the violinists. The relationship between noise discrimination scores, suppression values and high frequency thresholds were evaluated by Pearson or Spearman regression analysis. In addition, inferential statistics is only useful as a supplementary and type 1 error level is determined as 5%.

Results

The findings regarding age, gender, violin playing times, and tinnitus complaint belonging to the participants were presented in the method section. For the average hearing threshold in the control group of 500 Hz, 1,2 and 4 kHz was 10.15 ± 2.50 dB HL, and in violinists it was 12.09 ± 0.05 dB HL. There is no clinically relevant difference in speech frequencies between 125 and 8000 Hz between the right

Table 1 Mean ± standard deviation of hearing thresholds of the study and the control group

Frequencies	Hearing thresholds of the study group (dB HL)	Hearing thresholds of the control group (dB HL)	p
125 Hz right ear	5.60 ± 3.32	6.20 ± 3.89	0.56
125 Hz left ear	5.60 ± 3.32	5.40 ± 3.20	0.56
250 Hz right ear	6.20 ± 4.15	6.00 ± 4.33	0.83
250 kHz left ear	5.60 ± 3.90	5.40 ± 3.51	0.83
500 Hz right ear	5.20 ± 3.37	5.00 ± 3.53	0.86
500 Hz left ear	5.20 ± 3.37	5.40 ± 3.51	0.86
1 kHz right ear	6.00 ± 3.22	5.60 ± 3.32	0.85
1 kHz left ear	5.80 ± 4.00	5.80 ± 4.49	0.85
2 kHz right ear	5.60 ± 3.32	5.40 ± 3.20	0.83
2 kHz left ear	5.60 ± 3.00	6.00 ± 3.53	0.83
4 kHz right ear	6.20 ± 3.61	6.40 ± 4.45	0.83
4 kHz left ear	5.60 ± 3.32	5.40 ± 3.20	0.83
6 kHz right ear	5.80 ± 3.12	5.60 ± 3.00	0.66
6 kHz left ear	6.00 ± 4.08	6.20 ± 4.39	0.66
8 kHz right ear	5.60 ± 3.32	5.80 ± 3.73	1.00
8 kHz left ear	6.00 ± 3.53	6.00 ± 3.53	1.00

and left ear hearing thresholds in the violinists ($p > 0.05$) (Table 1).

Bone conduction hearing thresholds were obtained in accordance with air conduction hearing thresholds (Table 2). Although bone conduction hearing thresholds were within normal levels, no gap was detected that would indicate conductive hearing loss.

First, in the AFG test, which is one of the tests that evaluate the ability to discriminate the speech in background noise, the right and left ear scores of the participants in the study group are 24.00 ± 1.55 and 23.48 ± 2.20, respectively. In the control group, these values are 25.04 ± 1.49 and 24.88 ± 2.40 for the right and left ears, respectively. When these values were compared between the groups, clinically relevant differences were found in both of the ears ($p = 0.019$ for the right ear, $p = 0.037$ for the left ear). On the other hand, no clinically relevant difference was found between the right and left ears in the same participant ($p = 0.187$ for the study group, $p = 0.180$ for the control group) (Fig. 1).

When we examined the hearing thresholds of right and left ear obtained with the high frequency audiometer,

Table 2 Mean ± standard deviation of bone conduction hearing thresholds of the study and the control group

Frequencies	Hearing thresholds of the study group (dB HL)	Hearing thresholds of the control group (dB HL)	p
500 Hz right ear	2,80 ± 2.53	3.00 ± 2.50	0.777
500 Hz left ear	2,80 ± 2.53	3.20 ± 2.84	0.662
1000 Hz right ear	4,20 ± 3.12	4.40 ± 3.33	0.843
1000 Hz left ear	4.10 ± 3.20	3.40 ± .2.78	0.690
2000 Hz right ear	3,40 ± 2.78	4.20 ± 3.12	0.370
2000 Hz left ear	4,00 ± 2.89	3.80 ± 3.32	0.757
4000 Hz right ear	4,60 ± 3.20	4.60 ± 3.51	0982
4000 Hz left ear	4,00 ± 2.89	5.00 ± 2.89	0.886

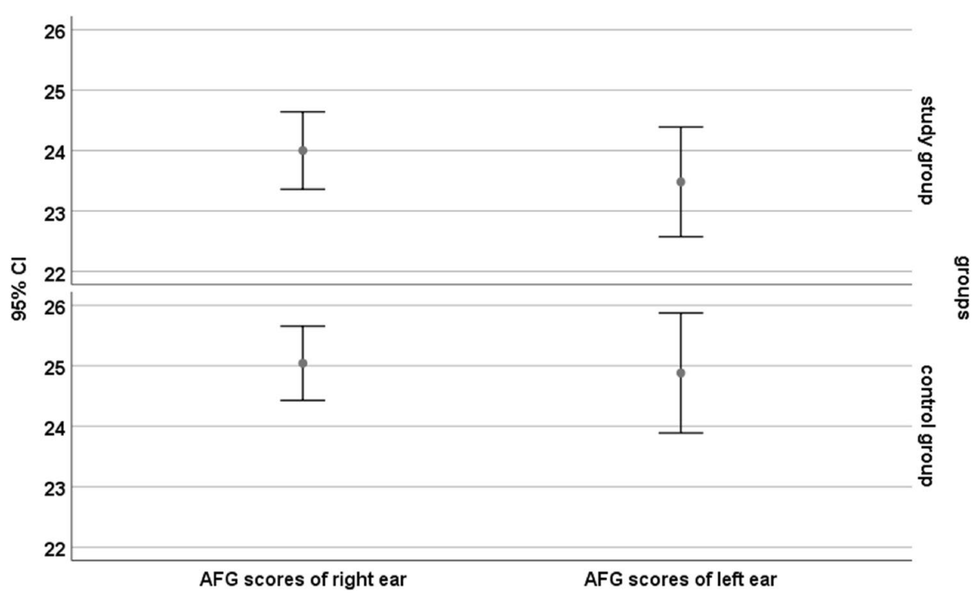

Fig. 1 AFG scores of the study group and control group on the right and left ear

Table 3 Mean and standard deviation of high frequency hearing thresholds of the study and the control group

Frequencies	Hearing thresholds of the study group (dB HL)	Hearing thresholds of the control group (dB HL)	p
10 kHz right ear	18.60 ± 3.39	14.60 ± 3.20	0.000*
10 kHz left ear	19.00 ± 3.23	15.00 ± 3.23	0.000*
11.2 kHz right ear	18.60 ± 3.07	15.20 ± 3.67	0.001*
11.2 kHz left ear	17.60 ± 3.27	15.20 ± 3.06	0.010*
12.5 kHz right ear	21.00 ± 3.23	18.00 ± 3.23	0.002*
12.5 kHz left ear	21.20 ± 4.15	18.80 ± 3.32	0.029*
14 kHz right ear	26.80 ± 3.50	23.40 ± 3.45	0.001*
14 kHz left ear	26.20 ± 3.62	22.00 ± 4.08	0.000*

*$p < 0.05$, there is a clinically relevant difference

Table 4 Signal-to-noise ratios of DPOAE responses of the study and control group

DPOAE signal to noise ratio (dB)	The study group		The control group		p
	Mean	Standard deviation	Mean	Standard deviation	
1 kHz right ear	12.64	2.03	13.52	3.26	0.260
2 kHz right ear	9.85	1.71	10.84	2.34	0.094
4 kHz right ear	8.02	1.36	9.42	1.57	**0.002***
6 kHz right ear	6.22	1.34	7.22	1.00	**0.004***
1 kHz left ear	12.40	2.10	13.84	3.04	0.057
2 kHz left ear	9.54	1.83	10.52	1.96	0.072
4 kHz left ear	8.28	1.49	9.44	1.60	**0.011***
6 kHz left ear	6.16	1.05	7.05	0.84	**0.002***

*$p < 0.05$, there is a clinically relevant difference

Table 5 Suppression amounts of DPOAE responses of the study and control group

Suppression amount of DPOAE responses (dB)	The study group		The control group		p
	Mean	Standard deviation	Mean	Standard deviation	
1 kHz right ear	1.86	0.47	2.24	0.66	**0.024***
2 kHz right ear	1.96	0.42	2.23	0.59	0.066
4 kHz right ear	1.27	0.49	1.27	0.47	1.000
6 kHz right ear	0.92	0.37	0.89	0.31	0.776
1 kHz left ear	1.88	0.45	2.20	0.54	**0.028***
2 kHz left ear	1.82	0.42	2.11	0.50	**0.031***
4 kHz left ear	1.29	0.38	1.29	0.40	0.971
6 kHz left ear	0.86	0.28	0.89	0.29	0.693

*$p < 0.05$, there is a clinically relevant difference

clinically relevant differences were found between the groups at all frequencies (10 kHz, 11.2 kHz, 12.5 kHz, 14 kHz). In the study group consisting of participants playing violin, high frequency hearing thresholds in both ears were clinically relevantly worse than the control group. (Table 3).

There is no clinically relevant difference in high frequency hearing thresholds when examined by Paired-Samples *t* test between the right and left ears among the violinists in the study group ($p > 0.05$).

DPOAE results are presented in two ways; the first DPOAE SNRs were recorded before noise was presented (Table 4). Subsequently, DPOAE SNRs were determined in the presence of noise from the contralateral ear. The suppression amounts were calculated by subtracting the SNRs obtained in the presence of noise from the initial condition (Table 5).

Accordingly, there were no clinically relevant differences between DPOAE SNRs between the study group and the control group in both ears at 1 kHz and 2 kHz frequencies. However, the DPOAE SNRs at 4 kHz and 6 kHz frequencies were clinically relevantly lower in participants playing the violin. It can also be stated that the SNRs from 1 to 6 kHz continue to decrease (Table 5).

When the amount of suppression obtained after the noise is presented, that is, the decrease in responses compared to the initial situation of DPOAE responses, there were clinically relevant differences between the study and control groups in both ears at 1 kHz ($p = 0.024$ at the right ear, $p = 0.028$ at the left ear). In addition, a clinically relevant difference was found between the two groups in the left ear at 2 kHz ($p = 0.031$). Accordingly, suppression amounts of the violinists were statistically lower. In other respects, there were no clinically relevant differences between the two groups in the remaining frequencies.

There is no clinically relevant difference between the right and left ears among the individuals playing violin in the study group in terms of DPOAE responses and suppression amounts ($p > 0.05$).

When the relationship between AFG scores and suppression amounts was examined for the purposes of the study, no statistically significant relationship was found in the both ear ($p > 0.05$). For the purposes of the study, when the relationship between HF thresholds and suppression amounts was examined, a statistically significant relationship was found between the 12.500 Hz thresholds in the left ear and the amount of left ear suppression at 6000 Hz ($p=0.005$, $r=-0.540$). In addition, a statistically significant correlation, not the cause an effect, was found between the 11,200 Hz thresholds in the right ear and the suppression amounts at 2000 Hz ($p=0.004$, $r=-0.399$), and between the 14.000 Hz thresholds and the suppression amounts at 6000 Hz ($p=0.038$, $r=-0.295$). Finally, it was investigated whether there is a relationship between high frequency hearing thresholds and AFG scores, which is the correct repeated word score in speech discrimination in noise. Accordingly, a statistically significant correlation was found between AFG scores obtained in the left ear and 10,000 Hz hearing thresholds in the left ear ($p=0.022$, $r=-0.323$), and between AFG scores obtained in the right ear and 14,000 Hz hearing thresholds in the right ear ($p=0.015$, $r=-0.342$).

Discussion

In the current study, it has been investigated whether there is a difference between the violinists with their peers who have normal hearing and are not related to music in their life, in terms of discriminating speech in noise and medial olivocochlear efferent performance via suppression in otoacoustic emission. According to violinists, sound conduction via bone conduction improves hearing violin sound noticeably. However, no clinically significant difference in pure tone audiometer air conduction and bone conduction hearing thresholds was detected between the study and control groups in the current study. This could be because the increase in perceived loudness of the violin sound psychoacoustically cannot be fully reflected on the audiometric findings.

One of the first points to be mentioned here is why research was conducted with an isolated musical group, such as violinists. To put forward a few reasons for this, the violin is one of the musical instruments that is played closest to the individual, and therefore, it is thought to affect the hearing performance more. Moreover, musicians who are in a symphony orchestra and play different musical instruments, as mentioned in the introduction, will not be able to standardize the effects of music in improving or worsening the hearing performance. In our opinion, however, in a single instrument, such as a violin, the distance to the player, the intensity and frequency range of sound are clearer and provides more homogeneous conditions for a research. Thus, in a study [24, 30], the difference between solo performance and playing in a music group or an orchestra is emphasized as follows; in non-solo performances, the voices, rhythms and melodies of other instruments should be distinguished and they should have the ability to maintain attention in this variety.

Apart from some studies [11, 14, 17], there are many researches in which hearing performances are evaluated by grouping participants on general title as musicians and non-musicians [1, 2, 19, 22, 38].

If we discuss the findings in order, first, in the AFG test, unlike other studies [22, 24, 33, 34, 37], the violinists had worse results than the controls. Although there were many studies [22, 24, 33, 34, 37] that advocated the positive effects of music-related skills and music training on hearing abilities, the opposite results were found in this study. The poor ability to discriminate speech in noise in our current study might be the result of exposure to the inner ear structures and noise exposure. The violin, which is one of the closest musical instruments to the person, might have caused noise-related damage in the inner ear due to the level of sound it generates, as high frequency hearing thresholds were also obtained worse in the violinists. For similar reasons, the outer hair cell responses were weaker without suppression at 4 kHz and 6 kHz frequencies of DPOAE in the violinists, such as another study [11]. Based on this, it can be said that the structural and / or functional problems that may occur due to noise in the regions of the cochlea representing high frequencies may affect the auditory responses adversely.

In relation to this, in some studies [4, 18, 26, 32] that investigate whether early hearing loss due to noise can be measured with a high frequency audiometer, or whether musicians are affected by high frequency hearing thresholds, noise-related hearing loss and worsening of high frequency hearing thresholds have been observed in musicians who have been exposed to high intensity instrument sounds for a long time. The auditory system can be adversely affected due to insufficient knowledge of musicians in this regard, and not taking precautions with hearing protection tools. Indeed, in the current study, the high frequency hearing thresholds were higher in the violinists.

The investigation of the medial olivocochlear efferent system with contralateral suppression in otoacoustic emission in musicians is available in a limited number of studies in the literature. To our best knowledge, this study was the first study about medial olivocochlear efferent system in an isolated group, such as violinists. When similar studies were examined, the opposite findings were obtained in the current study; whereas in other studies [2, 17], the amount of suppression was higher in musicians, in our current study, the lower values were obtained in the violinists. This situation is thought to be similar to the reasons for the increase in high frequency hearing thresholds and poor speech discrimination skills as mentioned earlier.

The medial olivocochlear efferent system is considered as the protective functional role of the "hardening" of outer hair cells by themselves. As mentioned earlier, cochlear micromechanics are regulated by the medial olivocochlear efferent system, which affects the contractility of outer hair cells. The outer hair cells in the organ of corti can lengthen and shorten in response to potential intracellular changes, and these properties are responsible for the amplification of vibrations caused by acoustic stimuli. At this point, in the presence of high intensity noise, a decrease in the hair cells' contractility, that is, the absence of suppression, is a pathological event that can predict effective hearing system dysfunction and means that the medial olivocochlear system is functioning poorly. The reason for the increase in hearing thresholds at high frequencies, the poor performance of the medial olivocochlear efferent system, and their low amplitude in high frequency DPOAE responses in violinists can be explained by this information.

The reason why the amount of suppression is statistically different between the two groups, especially at 1 kHz, may be due to the decrease in the DPOAE SNRs towards 4 kHz and 6 kHz, and the responses are still weak at these frequencies without suppression. The relatively high DPOAE response amplitudes at 1 kHz may have helped us to understand the difference more clearly, with a higher amount of suppression also in the presence of noise.

There were no clinically relevant differences between the right and left ear in terms of pure tone hearing thresholds, high frequency hearing thresholds, DPOAE response amplitudes, and suppression levels in the violinists, all with right hand dominance. Although past studies have determined the difference between the two ears [25], the current study's missing difference could be attributed to the late beginning age of the participants, the short daily playing time, and the unprofessional nature of the participants. This may be due to the fact that the distance difference between the ears is not sufficiently high in the violin hold position.

Interestingly, despite normal hearing thresholds in violinists, high thresholds in high-frequency audiometers, low amplitudes in DPOAE 4–6 kHz responses and poor performance of the medial olivocochlear system and consequently difficulties in speech discrimination in noise can be a guide for investigating other problems, such as cochlear synaptopathy. Unexpectedly, hearing thresholds appear to be raised in violinists at high frequencies of 10 kHz and above, although there was no change at 8 kHz. The cause of such a "skip" is most likely due to regional impairment of the cochlear basilar membrane. DPOAE tests, on the other hand, were influenced by frequencies below 8 kHz. This could be, because the sensitivity of DPOAE and high frequency audiometer tests differs. In addition, DPOAE is an objective sensitive test in which the cochlea's nonlinear amplification mechanism is evaluated using a probe placed in the ear canal and the response is recorded using the same probe. If there is cochlear defect, DPOAE may be clearer to reflect this. The high frequency audiometer, on the other hand, is a subjective test based on a person's response. This defect may not be as reflected in the thresholds and may not be functionally revealed in the case of cochlear degeneration, particularly in the early stages of degeneration. The stronger arguments can be presented in future studies by include DPOAE measurements at high frequencies of 10 kHz and above. ***Dünnwald (1991) offered four frequency regions that he believed were crucial in determining sound quality: The frequency ranges are 190–650, 650–1300, 1300–4200, and 4200–6400 Hz [6]. As a result, frequencies with hearing thresholds that can be affected are expected to be in this range; however, the study's findings revealed that there was high frequency impairment, as well as DPOAE responses that were affected. This condition can be discussed not only by the frequency characteristics of the violin, which is one of the most human-like instruments, but also by its high sound intensity. As a matter of fact, studies on cochlear synaptopathy in musicians have observed a decrease in auditory brainstem response I. wave amplitudes and poor performance in speech discrimination in noise despite normal hearing thresholds [3, 35]. Since the main purpose of the present study was not to reveal cochlear synaptopathy, evaluations such as auditory brainstem response test were not made. Considering the results, although it has the biggest limitation in this respect, it is still very important in terms of guidance on hearing performance of musicians for future studies.

The original aspects of the study are the fact that a comprehensive audiological investigation was used to discriminate the speech in noise, contralateral suppression in otoacoustic emission and high frequency audiometer tests. In addition, it is among the limited number of studies [27] conducted with violinists who are not in general musicians. Furthermore, with this detailed examination of young violinists, this research is particularly useful in terms of providing early diagnosis and treatment of probable auditory abnormalities.

The lack of larger sample size and extensive tests for speech discrimination skills can be considered among the limitations of the study. In future studies, it is recommended to study with more participants and different music groups, including cortical tests, noise listening tests with detailed SNRs.

The current study has been shown that high frequency hearing thresholds are higher in the violinists; also the responses at 4 kHz and 6 kHz frequencies are weak in DPOAE, and most importantly, the function of the medial olivocochlear efferent system is inadequate based on the observation that suppression seems lower. Accordingly, it has been suggested that comprehensive audiological evaluation and routine controls are very important for musicians. Long-term exposure to high-level noise created by the violin, one of the closest musical instruments, can cause high frequency hearing loss, decreased DPOAE response amplitudes, and poor medial olivocochlear function in violinists.

This study sheds light on the significance of routine and extensive audiological follow-up for young musicians.

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Declarations

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval The Non-Interventional Clinical Research Ethics Committee of Gazi University approved this study with the decision number 507.

Informed consent The informed consent approvals of all participants were obtained from themselves.

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