

Original articles

Audiological and electrophysiological assessment of professional orchestral musicians

Alessandra Giannella Samelli¹<https://orcid.org/0000-0002-7164-8942>**Camila Maia Rabelo¹**<https://orcid.org/0000-0001-5431-8071>**Liliane Aparecida Fagundes Silva¹**<https://orcid.org/0000-0001-8985-0447>**Denise Gonzaga¹**<https://orcid.org/0000-0002-9301-7340>**Joyce Miranda Santiago¹**<https://orcid.org/0000-0002-6334-0147>**Fernanda Cristina Leite Magliaro¹**<https://orcid.org/0000-0003-0627-4320>**Carla Gentile Matas¹**<https://orcid.org/0000-0002-9408-7172>

¹ Universidade de São Paulo, Faculdade de Medicina - FMUSP, Departamento de Fisioterapia, Fonoaudiologia e Terapia Ocupacional, São Paulo, São Paulo, Brasil.

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Corresponding address:

Alessandra Giannella Samelli
Rua Cipotânea, 51, Cidade Universitária
CEP: 05360-160 - São Paulo, São Paulo,
Brasil
E-mail: alesamelli@usp.br

ABSTRACT

Purpose: to verify whether the frequent musical exposure can impair peripheral and central auditory pathway responses in professional orchestral musicians.

Methods: 45 male individuals from 19 to 40 years old participated in the study. They were divided into two groups: one comprising 30 orchestral musicians who played strings or wind instruments, and another with 15 nonmusicians. The two groups were submitted to both conventional and high-frequency pure-tone audiometry, transient-evoked otoacoustic emissions, and frequency-following response. The results were subjected to descriptive and inferential statistical analysis, using the one-way ANOVA unmatched samples parametric test, with a 5% significance level.

Results: no significant differences were observed between the hearing thresholds in both conventional and high-frequency audiometry and frequency-following response. However, there were statistically significant differences between transient-evoked otoacoustic emission responses, with lower responses to musicians in comparison to the nonmusician group.

Conclusion: the results suggest that frequent musical exposure experienced by orchestral musicians can impair the cochlear hair cells' function. Therefore, audiological monitoring is important to detect subclinical impairments.

Keywords: Music; Hearing; Electrophysiology; Hearing Loss; Cochlea

INTRODUCTION

The exposure to high sound pressure levels can cause auditory damage, leading to permanent hearing loss, besides other auditory symptoms as tinnitus and hyperacusis^{1,2}.

Music, although considered different from the noise for its spectral characteristics, when played in high sound pressure levels with long periods of exposure, can progressively and permanently injure the auditory system^{1,3}.

It is known that professional musicians constantly attend rehearsal and presentation environments, where the sound pressure levels surpass the intensity of 85 dB (A). Even though it is notorious that for jazz, pop and rock band musicians sound intensity is higher^{1,4,5} due to their use of amplification, research has been showing that the sound pressure levels reached in symphony orchestra presentations can range from 79 to 110 dB (A), even reaching peaks of 115 dB (A)⁶. Furthermore, to ensure a pleasant instrument performance, the musicians need to spend many hours studying and presenting, hence characterized as a risk environment for the development of hearing loss in this population.

With this in mind, some studies have evaluated the auditory symptoms among musicians, and tinnitus has been a very common complaint, affecting more than 50% of the individuals^{2,7-9}.

Moreover, other studies have evaluated orchestral musicians' hearing through conventional pure-tone audiometry, and the results showed that these individuals can present hearing loss through the years of exposure. In this sense, greater damage was observed for 4 to 8 Hz frequencies^{8,10,11}. On the other hand, a study noted hearing thresholds lower than 20 dB HL in music students¹².

It is known that cochlear impairment in its initial stage may not change pure-tone hearing thresholds in the conventional frequencies⁷. Thus, the auditory assessment through high-frequency audiometry (above 8 kHz), as well as transient-evoked otoacoustic emissions (TEOAE), is important to investigate whether there is cochlear impairment in this population.

The TEOAE responses are generated by the energy liberated from the cochlear outer hair cells, resulting from brief click stimulations¹³. When there are no middle ear pathologies, the absence or low TEOAE amplitude can indicate a cochlear dysfunction even before any relevant clinical evidence is perceived through pure-tone audiometry¹⁴. Some studies have observed that orchestral musicians can present

diminished TEOAE response amplitude, and the longer the exposure to such music, the worse can the cochlear impairment be^{10,11}.

Furthermore, to complement the battery of audiological examinations, the assessment of the auditory pathway's electrophysiological response is an important measure, as it can detect alterations throughout the auditory nerve to the brainstem¹⁵. The most employed acoustic stimulus to find such a measure is the click, because it triggers synchronic responses from a great number of neurons, representing a wide frequency range¹⁶. Despite this, the record generated by speech sounds through the frequency-following response (FFR) requires a synchronized neural response to be decoded; hence, it is an ideal method to study the neural basis of speech perception¹⁷.

Little is yet known about the influence exposure to music can have on symphony orchestra professional musicians' auditory pathway as a whole, since most of the studies involving musicians evaluate those of other musical genres, such as jazz, pop and rock. Moreover, they concentrate on assessing the peripheral portion of the auditory pathway.

Recently, studies have demonstrated that exposure to high sound pressure levels can cause damage to the auditory system, even when hearing thresholds measured through conventional audiometry are not lowered, due to a synaptopathy. Such alterations can lead to tinnitus, hyperacusis, and difficulties in speech-in-noise perception^{18,19}.

Therefore, it is essential to investigate whether there are auditory alterations in symphony orchestra musicians as well, considering both the conventional and high-frequencies hearing thresholds assessment, the cochlear function assessment, and the central auditory pathway functioning assessment. Hence, better guidance and hearing loss prevention programs can be offered to this population.

This study aimed at verifying whether frequent exposure to music can impair the responses of the central and peripheral auditory pathways in professional orchestral musicians.

METHODS

This is an observational cross-sectional study, approved by the Research Ethics Committee of the *Faculdade de Medicina da Universidade de São Paulo* – FMUSP, SP, Brazil, under process number 241/12. Before beginning the procedures, all the participants read and signed the Informed Consent Form.

A total of 45 individuals from 19 to 40 years old participated in this study. They were divided into two groups: the control group comprising nonmusicians (NMG), and the study group with professional orchestral musicians (MG), whose instruments had to be either strings or wind ones.

The inclusion criteria for the MG were: being a professional musician; being a member of an orchestra for over two years; being exposed to music at least once a week.

Regarding the exclusion criteria, these were the ones defined: reporting acoustic trauma; being exposed to occupational noise other than music; having a history of recurrent otitis media; having a previous history of otologic surgery; having conductive hearing loss or excessive cerumen in the external acoustic meatus.

The inclusion criterion for the NMG was the absence of professional-level exposure to music; as for the exclusion criteria, they were the same as those of the MG.

Hence, the MG comprised 30 male professional musicians, whose ages ranged from 19 to 36 years (22.25 ± 4.08); and the NMG comprised 15 male individuals whose ages ranged from 20 to 40 years (a mean of 24.87 ± 6.02).

In the MG, the daily exposure to intense music sounds averaged 5.75 hours, and the average time of musical experience was 10.75 years. As for the type of instruments, 15 individuals played string ones, and 15, wind ones; none of them used hearing protection devices when exposed to music.

To characterize the rehearsal environment, the sound pressure levels were measured during two rehearsals in different days, with the Svantek's™ SV 102 equipment, configured to A-weighting, low response, maximum daily exposure (8 hours) of 85 dB (A), exchange rate equal to 5 dB. The dosimeter was placed ahead of and behind the orchestra, with a measuring time of 180 minutes. The measures observed ranged from 74.1 to 103.2 dB (A), with mean Leq of 87.3 dB (A).

Concerning the procedures in this research, all the participants filled out a questionnaire on their age, gender, schooling, previous medical and occupational history, and musical activities such as daily rehearsing time, sound intensity level, weekly participation in musical activities, type of instrument played, and use of hearing protection device.

The auditory assessment first included otoscopy, and then all the participants were submitted to acoustic

immittance measuring to dismiss any conductive impairment and select the candidates based on the exclusion criteria. Thus, the normality criteria were the presence of a type-A tympanometric curve and ipsi- and contralateral acoustic reflexes²⁰.

Pure-tone hearing thresholds were assessed with the standard audiometry technique in an acoustically treated room using a clinical audiometer (Grason-Stadler's GSI 61). The hearing thresholds measured were for the conventional 0.25 to 8 kHz frequencies, as well as the 9, 10, 12.5, 14, 16, 18 and 20 kHz high frequencies. The hearing thresholds considered within limits of normality were those lower than 25 dB HL²¹.

The transient-evoked otoacoustic emissions (TEOAE) were measured using an ILO 292 Plus OAE Analyzer, with nonlinear click stimulus at 80 dB SPL level. The present responses were considered when the signal-to-noise ratio was greater than 3 dB SPL. The participants were assessed in a sound booth inside a silent room.

The auditory electrophysiological assessment was conducted through the frequency-following response (FFR), using the Intelligent Hearing Systems' two-channel Smart EP. The procedure took place in an acoustically treated room with the participants comfortably seated in a reclining chair. They were instructed to gaze at an image placed approximately one and a half meter away from their eyes, to minimize eye movement.

For this assessment, their skin was cleaned with an abrasive paste. Then, the electrodes were fixed to the surface with conductive paste and microporous tape. The electrodes' positioning followed the international 10-20 standard: the reference electrode was fixed at Fpz, the ground electrode on the forehead, and the active electrodes on the left and right mastoids (M1 and M2).

The stimulus used was the syllable /da/, lasting 40 ms, in alternated polarity, monaurally presented at 80 dBnHL, at a presenting rate of 11.1 stimuli per second, totaling 3,000 stimuli (three 1,000-stimulus sequences), presented through TDH-49 supra-aural earphones. The recording window lasted 60 ms, 150 K gain, 100 Hz high-pass and 3000 Hz low-pass filters. The three tracings obtained were selected and added, and in the resulting trace the V, A, C, D, E, F and O waves were identified, which were analyzed regarding latency, using the normality offered by the Navigator-Pro²² equipment as the parameter.

The results were submitted to statistical analysis. The quantitative data were evaluated through the mean value and standard deviation. For the inferential analysis, the one-way ANOVA non-matched sample parametric test was used. The significance level was set at 5% ($p < 0.05$).

RESULTS

Initially, the difference in age between the groups was analyzed. They were homogeneous, with no statistically significant difference between them in this variable (p -value = 0.091).

The data collected in the anamneses showed that, regarding auditory symptoms, 55% of the musicians complained of tinnitus, 25% of an itchy ear, and 37% of earache. Moreover, 33.3% of the musicians complained of difficulties in speech-in-noise perception, and 60% of them complained of discomfort in the presence of

intense sounds. None of the musicians reported using any hearing protection device in the rehearsals or presentations.

Concerning the audiological procedures, first, each ear's results were separately analyzed. Considering that the results obtained in the right and left ears had parallel responses and that there was no statistically significant difference between the ears (p -value > 0.05), the data were grouped. Hence, the results referring to the MG correspond to the data from 60 ears, whereas those of the NMG correspond to the data from 30 ears.

The results obtained in both evaluated groups revealed hearing thresholds for the conventional frequencies (0.25 to 8 kHz) within normality. When the audiometric results were compared, both for conventional pure-tone and high-frequency audiometry, no statistically significant differences were observed between the MG and NMG (p -value > 0.05) (Tables 1 and 2).

Table 1. Comparison of the conventional pure-tone audiometry thresholds between both groups

Conventional pure-tone audiometry	Group	Mean (dB HL)	Standard Deviation	p-value
0.25 kHz	NMG	6.50	3.60	0.148
	MG	4.50	4.60	
0.5 kHz	NMG	5.10	4.30	0.732
	MG	4.64	4.20	
1 kHz	NMG	5.80	5.09	0.506
	MG	4.86	4.08	
2 kHz	NMG	4.70	5.40	0.599
	MG	3.93	4.16	
3 kHz	NMG	3.90	4.30	0.375
	MG	2.57	4.87	
4 kHz	NMG	7.00	5.60	0.055
	MG	3.86	4.75	
6 kHz	NMG	7.10	6.20	0.708
	MG	6.14	8.81	
8 kHz	NMG	4.80	4.90	0.500
	MG	3.71	5.16	

One-way ANOVA test

Legend: NMG-Nonmusicians group; MG-Musicians group; kHz- Kilohertz; dB HL: decibel hearing level

Table 2. Comparison of the high-frequency pure-tone audiometry thresholds between both groups

High-frequency pure-tone audiometry	Group	Mean (dB HL)	Standard Deviation	p-value
9 kHz	NMG	9.6	5.8	0.213
	MG	7.07	6.57	
10 kHz	NMG	8.7	7.3	0.452
	MG	7	6.99	
12.5 kHz	NMG	10.2	12.3	0.279
	MG	7.21	6.12	
14 kHz	NMG	10.7	15.8	0.332
	MG	7	9.53	
16 kHz	NMG	10.6	10.4	0.723
	MG	9.29	12.17	
18 kHz	NMG	10.3	9	0.930
	MG	10.56	9.46	
20 kHz	NMG	2	3.7	0.439
	MG	3.06	4.56	

One-way ANOVA test

Legend: NMG-Nonmusicians group; MG-Musicians group; kHz- KiloHertz; dB HL: decibel hearing level

The TEOAE results demonstrated statistically significant differences in all frequencies evaluated (p -value < 0.05), with higher response amplitudes in the NMG. Only in the response parameter, despite the amplitude being higher in the NMG, the p -value did not reach the significance level adopted in this study (p -value = 0.2447) (Table 3).

Regarding the FFR data, it was observed that the latency values for all waves were within normality standards in both groups. When comparing the results obtained between the groups, no statistically significant differences were observed (p -value > 0.05) (Table 4).

Table 3. Comparison of the transient-evoked otoacoustic emissions responses between the two assessed groups

TEOAE	Group	Mean (dB SPL)	Standard Deviation	p-value
1 kHz	NMG	13.62	7.55	0.0038*
	MG	5.96	8.1	
1.5 kHz	NMG	20.16	5.73	0.0000*
	MG	7.68	8.68	
2 kHz	NMG	19.62	4.86	0.0000*
	MG	7.84	7.55	
3 kHz	NMG	17.77	4.98	0.0000*
	MG	6.61	6.61	
4 kHz	NMG	12.59	5.36	0.0000*
	MG	2.55	7.2	
Response	NMG	13.41	3.12	0.2447
	MG	8.13	17.1	

One-way ANOVA test

Legend: NMG-Nonmusicians group; MG-Musicians group; kHz- KiloHertz; dB SPL: decibel sound pressure level

Table 4. Comparison of the Frequency Following Response wave latencies with speech stimulus between the two assessed groups

FFR	Group	Mean (ms)	Standard Deviation	p-value
V	NMG	6.61	0.66	1.000
	MG	6.61	0.78	
A	NMG	7.95	0.56	0.605
	MG	8.08	0.88	
C	NMG	18.17	0.79	0.107
	MG	17.31	1.94	
D	NMG	22.93	1.19	0.775
	MG	23.03	1.06	
E	NMG	31.70	1.17	0.532
	MG	31.93	1.15	
F	NMG	40.03	1.68	0.668
	MG	39.87	0.82	
O	NMG	47.92	1.53	0.077
	MG	48.85	1.85	

One-way ANOVA test

Legend: NMG-Nonmusicians group; MG-Musicians group; ms-milliseconds

DISCUSSION

This study enabled symphony orchestra musicians who played string and wind instruments to have their hearing evaluated. Their rehearsal environment was characterized in terms of sound pressure levels. Moreover, possible audibility differences these individuals might have were investigated in comparison with nonmusicians, given the musician's exposure to music in high sound pressure levels.

It was verified that the sound pressure levels during the orchestra rehearsals ranged from 74.1 to 103.2 dB (A), with mean Leq of 87.3 dB (A). The values observed in this study are similar to those described in a literature review article⁶, which mentioned values ranging from 79 to 110 dB (A) in symphony orchestra presentations.

Although the mean time of exposure (five hours) and the mean sound pressure level in the rehearsal environment (87.3 dB (A)) are within the safety limits recommended by the NR 15 regulatory norm (85 dB (A) for up to eight hours)²³, it is known that every increase of 5 dB cuts by half the allowed exposure time limit. Thus, considering that the values measured reached 103 dB (A), this population's risk of developing hearing loss cannot be dismissed.

In this study, none of the musicians reported using specialized personal protective equipment, which agrees with previous studies that observed that the use of hearing protection devices is not usually welcome among musicians⁷. Some authors commented that in the orchestras the difficulty in using personal hearing

protection devices dwells in the need to listen to their own instrument, as well as the other musicians'. Furthermore, when the musical dynamic changed, it could be harder for the musicians to hear the lower sound intensity musical passages if they were wearing such protections; it would also be difficult for them to listen to the conductor during the rehearsals⁷.

In a study with five orchestras, it was observed that 94% of the participants were concerned about hearing loss. However, only 20% of the participants who presented auditory complaints and 6% of those who did not present them used hearing protection devices. The author further stated that motivation and training are necessary to increase adherence to the use of hearing protection devices among musicians⁹. Similarly, another study conducted with orchestral musicians noted an adherence of only 2% in wearing hearing protection devices⁸. Hence, an educative program must be developed along with these professionals, to grow in them the awareness about their auditory risks, as well as the necessary use of hearing protection devices specially developed for musicians, which would interfere less with the dynamics of their daily activity and at the same time prevent the development of hearing losses.

Concerning the main auditory complaints, it was observed that 55% of the musicians presented tinnitus. This percentage is similar to that found in other studies, in which the prevalence of this symptom in 51%⁸ and 53%²⁴ of the musicians was noted. Likewise,

tinnitus was mentioned as one of the main effects of excessive exposure to high-intensity music in São Paulo's Municipal Symphony Orchestra⁷. Moreover, in Laitinen's study, temporary tinnitus was the most common complaint, reported by 37% of the individuals, whereas permanent tinnitus was reported by 15% of the women and 18% of the men⁹.

A recently published systematic literature review observed prevalence of hearing loss – affecting mainly the 3 to 6 kHz frequencies – in 32% of the professional classical musicians. This study also observed that tinnitus was the main audiological complaint, with a prevalence of 25.8% in pop-rock musicians and 26.5% in classical musicians².

Regarding the other complaints, it was observed that 33.3% of the musicians reported difficulties in speech-in-noise perception, and 60% of them complained of discomfort in the presence of intense sounds. This agrees with the study by DiStadio et al.², which states that music, both as entertainment and as a profession, can not only cause hearing loss but also induce other auditory symptoms as tinnitus and hyperacusis.

Some studies have pointed out that prolonged noise exposure can change the ability to distinguish both speech and nonspeech sounds^{25,26}. Other studies that assessed the comprehension of speech with background noise, with normal-hearing individuals comparing those exposed to noise with those that were not, concluded that the group of exposed individuals had fewer right answers, suggesting an impairment in speech intelligibility in situations of unfavorable listening, even with hearing thresholds within normality^{25,27}. Comparing the findings of noise-exposed workers with those of the musicians assessed in this study, it can be suggested that, even though it is not noise, exposure to high-intensity music can have damaged speech-in-noise perception, which would explain the complaint reported by more than 30% of the musicians.

Analyzing the results of the conventional pure-tone audiometry, hearing thresholds within normality standards were observed in both groups. Moreover, in both conventional and high-frequency pure-tone audiometry, there were no statistically significant differences between the MG and the NMG.

This finding corroborates a study that did not observe differences between music and nonmusic students, whose hearing thresholds were lower than 20 dB HL in 83% of those evaluated in both groups¹².

Another two studies that assessed orchestral musicians observed hearing thresholds within normality for the conventional frequencies, even after many years of exposure. Nonetheless, a notch in 6 kHz frequency was noted, similar to that observed in noise-induced hearing loss^{28,29}.

Unlike the findings in this study, Pawlaczyk-Łuszczynska et al.¹⁰ found audiograms typical of noise-induced hearing loss in 28% of the musicians assessed. Similarly, another study observed bilateral hearing loss in 19.2% of the musicians⁸. Yet another study observed that more than 50% of the symphony orchestra musicians presented sensorineural hearing loss, with higher thresholds in the higher frequencies, in both conventional and high-frequency audiometry²⁴.

It should be highlighted that the individuals assessed in this study are from a young age group (mean of 22.25 years), different from the abovementioned studies, in which the mean age ranged from 35 to 44 years^{8,10,24}. Another study observed thresholds lower than 15 dB HL in a group of musicians; however, it verified hearing thresholds higher than this intensity in 4 to 8 kHz frequencies in individuals older than 40 years¹¹. Hence, age seems to be one of the main factors causing the disagreement between the mentioned studies.

Some authors⁷ observed that pure-tone audiometry assessment can present normal results even when the individuals have some complaint, considering that normality in pure-tone audiometry thresholds in individuals with tinnitus is not a deciding factor to dismiss the possibility of cochlear impairment⁷.

In this study, the TEOAE results revealed statistically significant differences between the groups for all frequencies assessed, with the MG presenting lower mean TEOAE responses in comparison with the NMG.

A study showed a decrease in the amplitude of TEOAE responses after the rehearsals, whose sound pressure level ranged from 75.6 to 83.1 dB¹¹. Likewise, in another study that estimated the cumulative noise through the years – the calculation was based on the years of exposure and the measured sound pressure levels, with the musicians classified as either low-exposure or high-exposure –, a tendency to the statistical significance of high-exposure musicians presenting lower TEOAE responses was observed¹⁰. These data, combined with this study's findings, suggest that musical exposure can impair cochlear functioning, even when the hearing thresholds are within normality.

Concerning central auditory pathway assessment through FFR, it was observed that all individuals presented results within the expected for normality, with no statistically significant differences between the groups.

A study that assessed the brainstem auditory electrophysiological responses in a group of professional rock/pop musicians verified that, although they presented lower hearing thresholds, as well as lower TEOAE amplitude, the brainstem auditory evoked potentials wave latencies were more precocious than those of nonmusicians. Based on these data, the authors suggested that musical training can make the acoustic signal be more easily transmitted through the auditory pathway³⁰. It should be emphasized that the stimuli used in this study are different from those of the study mentioned, which can partly explain the differences in the findings.

Thus, this study's results can suggest that the injury caused by exposure to high sound pressure levels takes place first in the cochlear hair cells, and only later the impairment would manifest in the central pathways. Hence, changes in hearing thresholds in pure-tone audiometry and alterations in electrophysiological responses would only be noticed after a time of sound exposure longer than that experienced by the individuals in this study, given that auditory stimulation through musical training can make sounds be transmitted more easily, and so postpone the identification of any alteration in FFR wave latencies.

The lack of a legally established sound exposure standardization specific for musicians can lead people to falsely assume that this type of working environment is free of auditory risks. Therefore, attention is called to the need for implementing an auditory conservation program for this occupational group – one that establishes specific safety norms, considering the number of weekly workdays, the daily working hours, and the sound pressure levels allowed in each presentation.

Furthermore, it is recommended that they be made aware of the importance of using hearing protection devices during rehearsals and presentations, as well as undergoing audiological assessment and monitoring. This includes the TEOAE measures, considering that these responses have been proving capable of reflecting subclinical findings, as the early-stage cochlear impairment, which cannot yet be detected through pure-tone threshold auditory.

CONCLUSION

The results suggest that the frequent musical exposure experienced by orchestral musicians can damage the cochlear hair cells' function. Thus, audiological monitoring is important, so as to detect subclinical alterations.

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