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Evaluation of the Hearing Function in the Orchestra Professional Musicians of the Teatro alla Scala in Milan

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Abstract

Background: *This study was conducted to determine whether occupational exposure to high sound levels, typical of an opera orchestra, can cause hearing loss.* **Methods:** *The orchestra professors at Teatro alla Scala in Milan underwent ear examinations, pure-tone audiometry, and other audiological tests. The hearing thresholds of these musicians were compared with those of populations not exposed to occupational noise and with populations exposed to industrial noise. Noise exposure levels were estimated through a phonometric survey conducted at our theater in 2011, which largely confirmed the exposure levels outlined in European guidelines.* **Results:** *The average audiometric thresholds of the orchestra musicians were slightly worse than the median thresholds of a healthy, non-noise-exposed population. In three subjects (2.8%), bilateral hearing impairment (PTA 0.5, 1, 2, 3, 4 kHz > 25 dB HL) was observed; in four violinists (3.7%) left unilateral hearing impairment was found. This rate is lower than the expected risk from similar industrial noise exposures. Comparing these audiometries with those from about ten years earlier shows that the hearing threshold decline in the study group is comparable to that caused by presbycusis.* **Conclusions:** *The risk of noise-induced hearing loss among professional orchestra musicians appears lower than predicted by the UNI ISO 1999:2015 standard. A few cases of hearing loss due to chronic acoustic trauma were noted, particularly among violinists who demonstrated a higher incidence of left unilateral hearing loss. The high levels of sound exposure and the presence of some hearing loss cases highlight the need for targeted preventative measures in this work activity.*

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1. Introduction

Prolonged exposure to high sound levels can lead to noise-induced hearing loss (NIHL). NIHL depends on the level and duration of exposure but also factors like age, medication use, pre-existing or concurrent ear diseases [1, 2], individual susceptibility, and genetics. Zhang et al. [3] showed that genetic susceptibility significantly influences NIHL occurrence.

A literature search on PubMed focusing on noise-induced damage in professional classical orchestra musicians identified 67 articles published from 1960 to 2025. Regarding risk, the literature generally agrees that professors of opera orchestras are exposed to high sound levels. Exposure levels are often above 85 dBA, and the use of hearing protectors (PPE) is uncommon in this artistic environment [4]. The European Guidelines for preventing hearing damage in the performing arts sector, implemented in Italy [5-6], indicate that weekly exposure exceeds 85 dBA for all instruments except the double bass; for some wind and percussion instruments the intensity is around 90 dBA. Concerning potential NIHL among music performers [7], especially among professional orchestra musicians, the existing literature is inconsistent, with differences in study populations and exposure durations. Hake [4] evaluated 200 orchestral players, of whom only 58 were involved in classical opera or symphony orchestras; the rest were students from academies, conservatories, or amateurs, with limited details on age, exposure time, and extent. Moore et al. [8] and Quian et al. [9] proposed corrective assessment criteria, particularly regarding exposure times. Exposure is rarely documented through work schedules and repertoire. Several studies have focused solely on exposure during live performances [10-11]. Others examine exposure during individual practice, which often occurs in suboptimal acoustic environments, such as standard classrooms [12]. In the literature, the concept of 'damage' is defined differently: for some authors it is the loss of 20 dB HL at a single frequency [13]. Conversely, others define it as an assessment relative to the expected loss per population. Some studies assess NIHL not through audiometric tests but using specially designed questionnaires [14], or through surveys generated by dedicated apps [4].

In the review by Behar et al. [15], challenges were identified in drawing general conclusions about the occupational risks faced by musicians due to inconsistent methods across studies, both in instrumentation and procedures, as well as variability in reported performance times. To assess the impact of noise on hearing, proper tests must be conducted following a sufficient rest period since the last exposure to ensure the complete reversibility of the temporary hearing threshold shift. Good clinical practice recommends an acoustic rest period of at least 16 hours before audiometric testing [16]. However, in musicians' hearing evaluations, maintaining this optimal acoustic rest time is often challenging because of logistical issues such as work schedules and the habit of continuous practice and preparation. Nonetheless, Behar [17] suggests that classical music can cause a threshold shift of approximately 11 dBHL, which recovers in about 55 minutes. Due to these variables, research on noise-induced hearing loss (NIHL) among orchestral musicians has produced inconsistent findings. Most studies do not report an increased risk of hearing loss, even though these musicians are exposed to high noise levels but typically do not wear hearing protectors during performances, unlike industrial workers. Recent research has also pointed to the possible presence of hearing disorders such as tinnitus, hyperacusis, and sound perception distortions (e.g., diplacusis), which may impair a musician's artistic abilities. Hyperacusis is defined as "abnormal sensitivity to everyday sounds or noises," which can make certain sounds seem "painfully loud" [18-19], regardless of hearing threshold [20-21], and can cause difficulty perceiving loudness, a situation that can be especially disorienting for an orchestra conductor or professor. Diplacusis involves pitch perception difficulties or distortions, which can severely impact a musician's career—particularly for violinists or conductors. Sensorineural deafness at high frequencies, often linked with tinnitus, may lead a musician to play too loudly, with disastrous effects on performance quality [22-23]. This study aims to make a significant contribution to evaluating the risk of hearing loss among classical orchestra musicians, based on

documented exposure levels, and to identify prevention strategies tailored for this specific context.

2. Methods

2.1. Fieldwork

The study involved 119 professional musicians from the orchestra of the Fondazione Teatro alla Scala in Milan. Each participant was informed about the study's purpose and procedures and signed an informed consent form. They also received a document regarding personal data processing (all forms are available on the Teatro alla Scala Foundation website). The Ethics Committee of the University of Milan gave a positive opinion on this study and approved the informed consent form during its meeting n. 48.23 on April 18, 2023. The study's methods and purpose were also explained to the management of the Fondazione Teatro alla Scala and the union representatives of the orchestral musicians. All procedures in this study adhere to relevant international and institutional ethical standards on human research and follow the Helsinki Declaration of 1975, revised in 2008. Participation was voluntary, and written informed consent to participate and publish the results was obtained from all participants. Their anonymity has been preserved.

2.2. Noise Exposure Assessment

The phonometric survey conducted at our theatre in 2011 largely confirmed the exposure data outlined in the European guidelines. The evaluation process adopted accounted for all aspects that influence sound exposure. After consulting with an artistic commission, three works were selected based on their acoustic load on the musicians: The Magic Flute (Light), Tosca (Medium), and Turandot (Heavy). The musicians were grouped by instrument family, except for the strings, due to the large number of instruments and their specific positions in the orchestra. During the measurements, carried out both in the pit during performances and rehearsals, and in the rehearsal room, sound level meters and dosimeters positioned on the same musicians were used. For The Magic Flute, two dosimeters and seven sound level meters were used, recording a total of 29 positions; for Tosca, three dosimeters and six sound level meters, with 27 recorded positions; and for Turandot, three dosimeters and eight sound level meters, totaling 34 recorded positions. Individual practice is a fundamental part of a musician's activity, therefore separate measurements were also performed on some instruments such as the violin, cello, double bass, oboe, and clarinet. The activity duration for each was determined by cross-referencing data from the theatre management and the musicians. It was found that 33.3% of working time was spent in the rehearsal room, 42.4% in the orchestra pit, and 24.2% in individual practice. Furthermore, musicians engage with different repertoires within the same week, performing various operas while preparing a new one. For this reason, for each instrument or family, different weekly noise exposure levels (Lex,w) were established, combining different operas. For example, for the violin, the minimum Lex,w involves 2 light works and 1 heavy work, while the maximum involves 2 medium operas and 1 heavy work. Estimated weekly exposure values during orchestra activities are summarized in Table 1. In conclusion, musicians are exposed to Lex,w during different working weeks, with variations across instruments or families within 2-3 dB(A). The measurements from the individual practice showed a marked difference in exposure for the violin between the left ear (92.2 dB(A)) and the right ear (81.4 dB(A)), while the difference for other instruments was much smaller or nonexistent.

2.3. Audiological Assessment

In the auditory evaluation protocol, each participant (as part of the health surveillance activities arranged by the Competent Doctor in accordance with DL n.81/2008 [24]) underwent a specialist audiological assessment lasting approximately 30 minutes, which included:

- anamnesis and subjective evaluation of one's hearing condition;
- specialistic audiological examination to detect tympanic objectivity (video-otoscopy performed by Interacoustics Video Otoscope mod. VIOT);

Table 1. Results of the phonometric survey carried out by the Teatro alla Scala Foundation in Milan. The LEX,w is estimated for three levels of acoustic load perceived by musicians for the type of artistic production performed, and the dosimetric data [Leq dB(A)] measured for single instruments during an individual study with the dosimeter microphone placed on both sides of the neck are indicated.

Instruments	Estimated weekly exposure values *[$L_{EX,w}$ dB(A)]* during orchestra activities			Exposure levels *[L_{eq} dB(A)]* during individual study measured with dosimeters worn on both sides of the neck	
	Mild	Medium	High	Left side	Right side
Violin	85.5	85.8	87.3	92.2	81.4
Viola	86.9	88.0	89.8	NV	NV
Cello	85.6	86.8	87.1	87.0	87.6
Double bass	79.2	80.1	80.8	81.3	81.4
Woodwinds	87.7	87.9	89.5	87.7 *(Oboe)*	86.9
				80.4 *(Clarinet)*	77.7
Brass	90.2	91.2	92.2	92.3 *(Horn)*	93.6
				90.7 *(Trumpet)*	93.4
Percussions	92.5	92.9	93.3	NV	NV

- tympanometry, to assess the function of the tympanic-ossicular system (Interacoustics Impedance Meter mod. AT235), the stapedial reflex was not recorded to avoid the onset of tinnitus, a rare occurrence but always possible given the high intensity of the acoustic stimulus according to the ANSI S3.39-1987;
- liminal threshold pure-tone audiometry (Interacoustics Clinical Audiometer mod. AC 40B) in a silent soundproof booth (UNI EN ISO 8253 1:2010) according to the ANSI S3.1-1999; ANSI S3.6-2018;
- study of acoustic otoemissions from distortion products (DPOAE), (Interacoustics Otoemission System mod. Lyra DP+TE);
- Dichotic Digit Test (DDT), to assess the integration of auditory information binaurally.

Participants were also asked to complete an online questionnaire based on Laitinen's [14], which covered various topics related to the musicians' working conditions, auditory issues (such as tinnitus, hyperacusis, sound distortions, diplacusis, and the sensation of occlusion), use of hearing protection devices, and difficulties experienced with their use. Audiometric tracings were assessed and classified according to the Merluzzi-Pira-Bosio method, as outlined in the SIMLII's "Guidelines for the prevention of hearing damage from noise in the workplace" [25]. The longitudinal assessment of the musicians' hearing thresholds involved comparing current audiometric tracings with those performed by the health service of Teatro alla Scala for the health surveillance of orchestra professional musicians from 2011 to 2019.

2.4. Statistical Analysis

Data were reported in a Microsoft Excel (v16.98) datasheet for dataset management and graph processing. The analysis involved correlating threshold pure tone audiometric values with personal variables, sound exposure from musical instrument use, and occupational seniority in the orchestra. The Normality Test (Shapiro-Wilk)[27], which returns a p-value > 0.05 if the data follow a normal distribution and a p-value < 0.05 if the data are non-normal, was used. To determine whether differences between groups were statistically significant, the Wilcoxon test was applied if the normality assumption was not met. If the data were normally distributed, the t-test was used instead. The statistical analyses were performed using RStudio (version 4.3.1). The comparison with the UNI ISO 1999:2015 standard [26] was conducted through the use of the software "Rumours.21" by

Casini S., which was used to assess the risk of hearing damage using the HTLAN (Hearing Threshold Level associated with Age and Noise) protocol.

3. Results

The study was conducted on 107 musicians because, out of the total population of 119 professors at the orchestra of the Fondazione Teatro alla Scala in Milan, one refused to participate, and 11 individuals were excluded due to unreliable and non-reproducible audiometric tests (3 individuals) or the presence of damage unrelated to noise exposure (8 individuals).

The main characteristics of the study subjects are shown in Table 2: 83 were males (78%) and 24 females (22%), with a mean age of 48.0 ± 10 years, and an average length of service in the orchestra of 27.1 ± 10.7 years. The average weekly noise exposure, based on different instruments and categorized according to the risk bands specified in Article 189 of DL n. 81/2008, is also illustrated.

3.1. Comparison With the Population Not Occupationally Exposed to Noise

Audiometric tests were collected from 6 groups, divided by gender and age. For each group, the average audiometric result was compared with the hearing threshold tracing for the group's average age, as reported in the ISO standards. Comparisons are shown in Figures 1a and 1b for male and female subjects, respectively.

1. with the standard of ISO 7029 taken from Database A of ISO 1999/2015, which represents "the statistical distribution of the hearing threshold of selected otologically normal populations (without signs or symptoms of hearing pathology) free of obstructive ear wax and without a history of occupational noise exposure". The threshold values are referred to as HTLA (Hearing Threshold Levels associated with Age)
2. with the statistical distribution provided by the B3 Database of the ISO 1999/2015 standard representing data from "an unselected population from an industrialized nation (Norway), otologically healthy and free of occupational noise exposure".

In all groups, the average thresholds of the orchestra's professional musicians at Teatro alla Scala were slightly worse than the 50th percentile of otologically healthy, non-noise-exposed populations, according to ISO 7029 and ISO 1999:2015 (Databases A and B3). The difference decreases with increasing age, while it is more pronounced in females up to age 50.

3.2. Assessment of the Incidence of Noise Damage

Audiometric tests were classified using the Merluzzi-Pira-Bosio (MPB) method, analyzing each ear separately to account for asymmetric exposure,

Table 2. Main characteristics of the sample and subdivision of the instruments by sound exposure class.

Subjects	Nr (%)	Age (years) Mean (range)	Weekly exposure $[L_{EX,w}$ dB(A)] Mean ± SD	Length of time (years) as orchestral musician (Mean ± SD)
Males	83 (78)	49 (23-62)	82.2 ± 3.6	27.7 ±10.8
Females	24 (22)	47 (29-62)	86.6 ± 1.3	24.9 ± 10.1
Instruments				
Double bass Keyboard	12(11.2)	47.6 (27-61)	< 85 dB	24.9 ± 9.7
Violin, Cello	46 (43)	49.5 (23-61)	85-87 dB	27.2 ± 10.4
Harp, Viola Woodwinds	32 (30)	51.7 (27-62)	87-90 dB	30.3 ± 8.6
Brass Percussions	16 (15)	43.6 (28-60)	>90 dB	22.2 ± 13.9

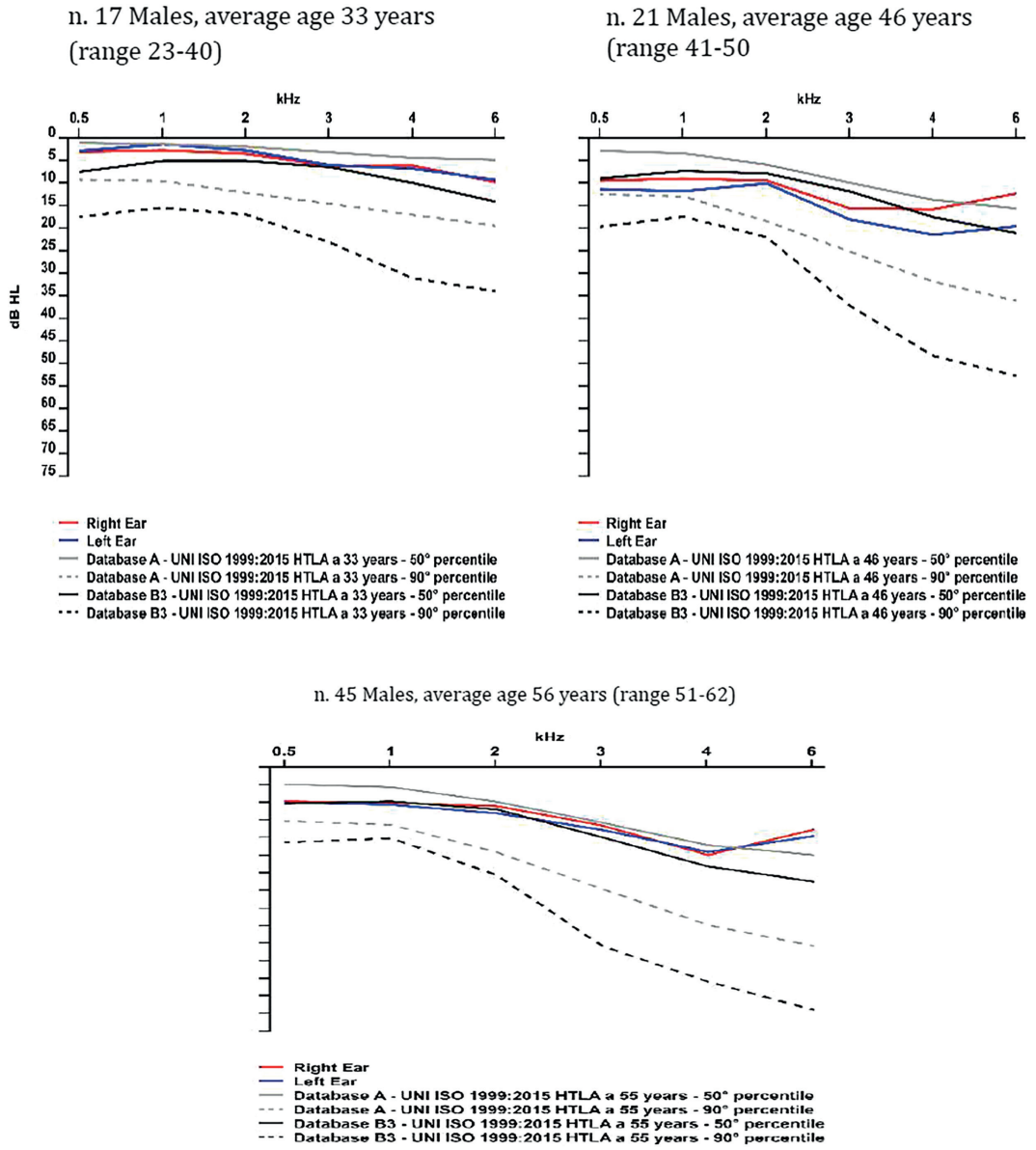

Figure 1a. Comparison of the average audiometric curves of the male population divided by age group with those of an otologically healthy reference population not exposed to noise (database A and B3 of the UNI ISO 1999/2015 standard.

especially among violinists, since asymmetric exposure to asymmetric instruments has been reported in the literature and was confirmed by the phonometric survey conducted at Teatro alla Scala.

Normal hearing (classes 0 and 1 A) was detected in 66.3 % of cases; the percentage of age-related hearing loss (class 8, presbycusis) was 10.3 %, while noise hearing impairment of varying degrees (classes 2 to 6, mono or bilateral) occurred in 23.3 % of the subjects. Noise hearing deficit was present in 25.3% of male musicians and 16.6% of female musicians;

- 10 subjects presented bilateral deficits, of which 50% were slightly asymmetrical,
- 8 have right-sided unilateral deficits, all of which are minor-class 2A,
- 7, of which 6 violinists, have left-sided hearing loss.

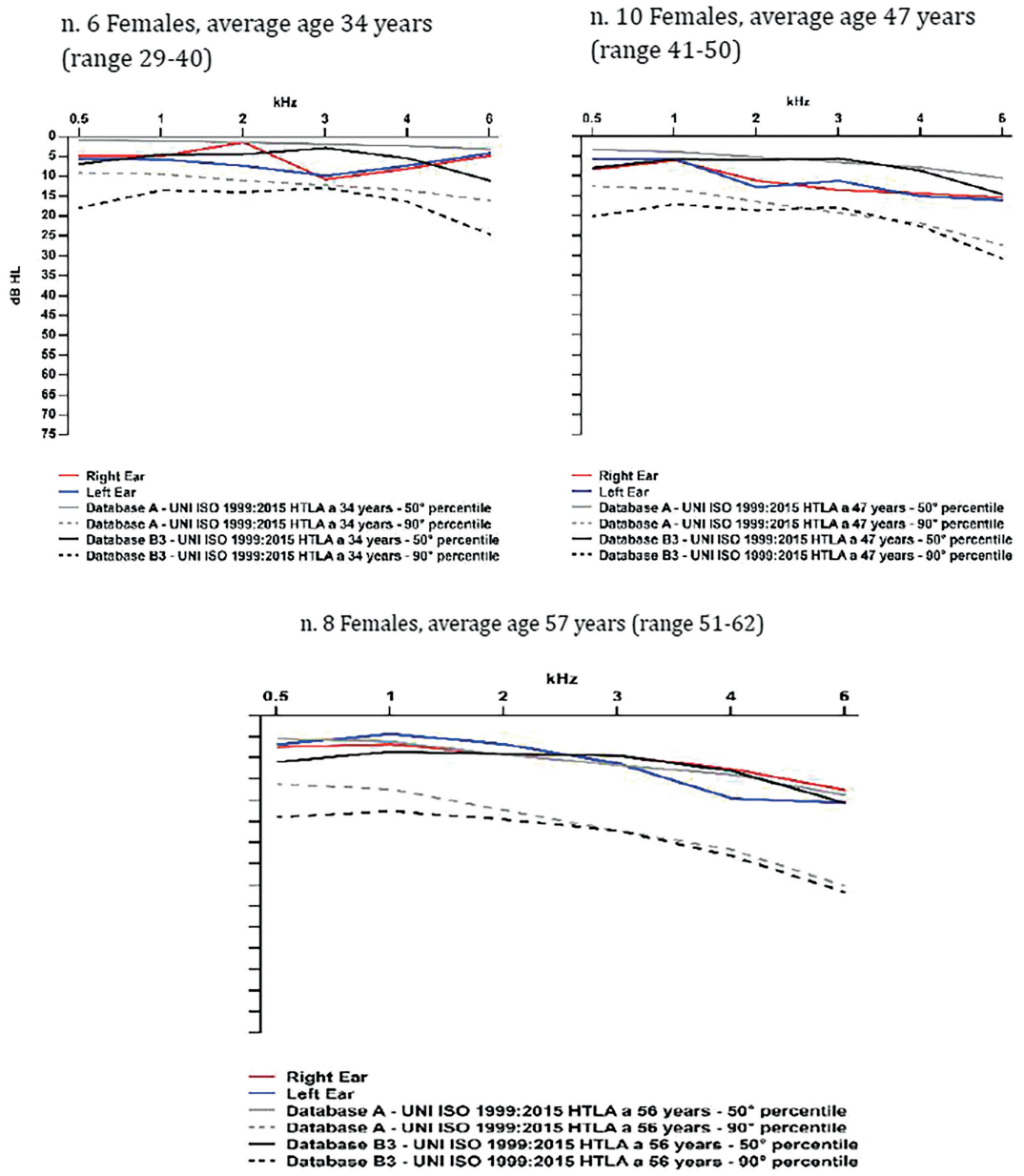

Figure 1b. Comparison of the average audiometric curves of the female population divided by age group with those of an otologically healthy reference population not exposed to noise (database A and B3 of the UNI ISO 1999/2015 standard.

According to the Merluzzi-Pira-Bosio (MPB) method, class 2 subjects have minimal hearing impairment, without impairment of comfortable social audibility, and usually without a subjective sensation of hearing impairment. In contrast, class 3A or higher includes hearing impairments due to chronic acoustic trauma, with increasing difficulty in understanding conversational speech.

About hearing impairments of class 3A or higher we found:

- 5 subjects with bilateral hearing loss, 2 violas, 1 flute, 1 percussion (with Lex-w > 87 dBA), and one violinist (with Lex-w between 85 and 87 dBA);
- 6 left unilateral hearing impairments, all in violinists.

These results confirm the expectation that violinists experience greater NIHL on the left side. There is a statistically significant difference in hearing thresholds between the left and right ears of violinists, with the left ear often showing poorer hearing only for these musicians. In fact, the comparison between the left/right hearing thresholds of violinists and those of musicians playing symmetrical instruments was also statistically significant (p=0.02) (Figure 2). This aligns with the phonometric evaluation conducted (Table 1): for violinists, during individual practice, the sound in the left ear is more than 10 dBA louder than in the contralateral ear.

3.3. Comparison with ISO 1999:2015 Noise-Induced Hearing Loss (NIHL) Risk

The risk of hearing damage in our sample was compared with that expected for workers exposed to industrial noise of the same intensity and duration, using ISO 1999:2015 as a reference. This standard with the HTLAN (Hearing Threshold Level associated with Age and Noise) values, indicates hearing threshold levels related to age and industrial noise exposure (intensity and years of exposure). We used the average biological damage indicator, dB 25HL, as a reference value, considering hearing damage present when the average threshold elevation at the 5 frequencies (0.5, 1, 2, 3, 4 KHz) is equal to or greater than 25 dB HL. We then calculated the risk as the percentage of the population with a hearing threshold at or above this value.

For a group of workers exposed to industrial noise of the same intensity and duration as our musicians, the expected risk of damage (PTA 0.5, 1, 2, 3, 4 KHz > 25 dB HTL) is 10%. In our sample, the actual cases of noise damage were lower, at 6.5%, with three subjects (2.8%) showing bilateral damage and four subjects (3.7%) showing damage only on the left.

The incidence of hearing damage, considering all injuries likely related to occupational exposure, was 35% lower than expected. If only bilateral injuries are considered, the incidence is 70% lower.

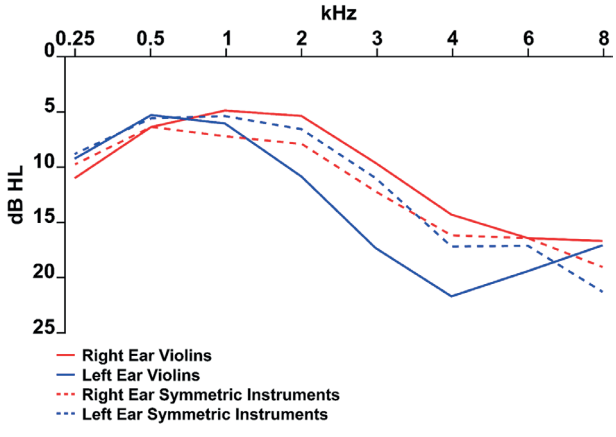

Figure 2. Comparison of average hearing thresholds (right/left) of violinists with those of symmetrical instrument players.

3.4. Longitudinal Assessment

For 80 musicians (61 males and 19 females), audiometric data obtained about 11 years earlier were available, allowing a longitudinal analysis to assess any worsening in hearing thresholds.

The male subjects at the first check-up had an average age of 40 years and an average orchestral length of service of 20.2 years; the females 35.6 and 15.4 years respectively.

The audiometric thresholds between the first examination and the one performed at an average interval of 11 years show minimal worsening bilaterally only at 3, 4, and 8 kHz in males (p-value < 0.01). No differences were observed among females. (Table 3).

The observed audiometric threshold changes are similar to the threshold increases expected from physiological aging [28]. According to the ISO 1999:2015 database A, the hearing threshold at the 50th percentile between ages 40 and 50 at 4 KHz increases by 8 dB HL for males and 5 dB HL for females; in our sample, these increases are never exceeded.

Table 3. Longitudinal audiometric thresholds average dBHL (decibel Hearing Level) of the population by gender.

		Right ear KHz					Left ear KHz				
Subjects	**Average value dBHL**	**2**	**3**	**4**	**6**	**8**	**2**	**3**	**4**	**6**	**8**
Males (61)	*1st evaluation*	9.5	13.3	16.5	21.1	19.6	9.1	12.9	19.4	21.8	20.7
	last evaluation	8.9	15.4	22.1	21.6	25.7	9.1	16.8	24.3	24.5	27
	p-value	ns	**	**	ns	**	ns	**	**	ns	**
Females (19)	*1st evaluation*	9.2	10	12.6	14.5	18.9	8.4	11	13.4	16	14.2
	last evaluation	9.7	13.7	12.6	14.7	16.6	11	13.4	18.4	15.3	16
	p-value	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns

** $P < 0.01$.

For individual cases, we considered a worsening due to noise exposure those tracings with an increase of more than 10 dB HL in the average hearing threshold at 2, 3, and 4 kHz after subtracting socio-presbyacusis (OSHA method modified by Brunetti, Menzio, and Morra) [29]. According to this criterion, 7 musicians (8.75%) showed changes likely due to noise: 1 harpist (right side), 4 violinists (left side), 1 horn (left), and 1 flute (left).

4. Discussion

The results of our study are consistent with the most frequently reported data in the literature [30-35], confirming that professional orchestral musicians are at a slightly increased risk of noise-induced hearing loss (NIHL) compared to the general population not occupationally exposed to noise, but at a lower risk than workers exposed to industrial noise of similar intensity and duration. The large sample size and the high percentage of adherence to the study (89.9%) are important indicators for the validity and reliability of the results.

The audiometric tests of NIHL in musicians typically exhibits the classical notch at 3–6 kHz, similar to that seen in occupational settings. However, NIHL in musicians tends to be more asymmetrical, influenced by factors such as the specific instrument played, seating position within the orchestra, and the intermittent nature of the exposure. In musicians playing instruments with high-frequency output, NIHL may also be evident at 8 kHz [18].

Johnson et al. [36] showed higher auditory acuity in orchestral musicians than in non-musicians by testing frequencies from 0.25 to 20 KHz; despite their continuous exposure to music, no significant deterioration in hearing thresholds was observed, nor were there notable gender or interaural differences.

In our study, asymmetrical exposure was particularly evident in violinists, with left ear sound levels reaching 92.2 dBA and right ear levels at 81.4 dBA during individual study, This pattern correlates with a significantly higher risk of left-sided unilateral hearing loss. The resulting hearing loss asymmetry is caused by direct exposure to the sound energy produced by the violin. Asymmetric deafness is also observed in hunters, with (in right-handed people) greater damage on the left side, even though the rifle is resting on the right shoulder. This is because, in this case, the source of the sound from the shot is in the barrel of the rifle, which is oriented to the left, and the right ear is protected by posture (raised shoulder and homolateral tilt of the head).

Suen et al. [37] in a general population of over 6,000 subjects older than of 20 years documented that the prevalence of asymmetrical hearing was higher among men and correlated with age: the left ear has a worse hearing threshold than the right ear even in individuals who have not been exposed to noise, especially at high frequencies. Bidelman [38] suggested a possible neurophysiological basis, proposing that the medial olivocochlear efferent system may be more active in the right ear, offering it greater protection against temporary threshold shifts.

In our data, as we noted, there are a few cases of hearing loss among musicians, almost exclusively

associated with occupational exposure above 87 dB(A).

Even in cases of left unilateral hearing loss, the risk of NIHL remains 35% lower than expected, confirming that the impact of classical music on hearing is less harmful than that observed with noise in industrial contexts. Only three cases of bilateral NIHL have been reported to INAIL (National Institute for Insurance against Accidents at Work) and recognized as occupational disease.

One possible physiological explanation for the lower incidence of NIHL in musicians compared to industrial workers is the acoustic profile of music, which differs significantly from that of industrial noise in terms of temporal structure, spectral complexity, and dynamic range. Music, in fact, spans a broader frequency spectrum, exhibits greater dynamic variability, and often includes periods of rest, thereby allowing partial cochlear recovery. [39]. Moreover, compared to industrial noise, music tends to have fewer impulsive peaks and more predictable temporal and spectral patterns, thereby reducing cochlear overload and potential damage [40]. Furthermore, compared to passive exposure to industrial noise, musical sound is self-generated through intentional motor activity, which may enhance activation of the medial olivocochlear efferent system, which plays a protective role by modulating cochlear amplifier gain and reducing overstimulation of outer hair cells. [38, 41, 42] A further hypothesis could be the influence of neuro-behavioral dynamics, which could explain the lower incidence of hearing damage for the perception of harmonic sounds, recognized and processed at the cortical level, compared to the perception of indistinct and unprocessed noises. The lower incidence of NIHL in musicians compared to industrial workers allows us to advance the hypothesis that it is not only the overall intensity of the noise that determines the damage, but also the composition of more or less harmonic frequencies could play a significant role. It could be hypothesized that certain situations trigger endolymphatic biomechanical alterations, which may be selectively harmful to specific topotonic areas. These aspects, still little known, could be better analyzed in a research project with the study of otoacoustic emissions [43] and with the evaluation of the 'dead regions' using the TEN test" [44].

Kähäri et al. [33] conducted a 16-year follow-up study of hearing thresholds in classical musicians and found no increase in hearing thresholds relative to normative values. This finding is similar to what was shown in our longitudinal evaluation. The reduced progression of hearing impairment over the years suggests that the cochlear auditory damage observed develops mainly during the first years of exposure. It should be kept in mind that in musicians, study can begin as early as 4-7 years of age, and artistic activity, with consequent exposure to acoustic risk, is very intense in the younger years in connection with prolonged study for examinations, competitions, and auditions. Similarly, Behar et al. [34], who measured hearing threshold variations over 5 years in orchestral musicians showed that thresholds did not change over this period, but emphasized that, in the orchestra he studied, measured exposures were usually <85 dB(A) as Leq.

The reduced progression of hearing impairment over the years suggests that the auditory damage of the cochlea observed develops mainly in the first years of exposure. It should be kept in mind that in musicians, study can begin as early as 4-7 years of age and artistic activity, with consequent exposure to acoustic risk, is very intense in the younger years in connection with prolonged study for examinations, competitions and auditions

Recently, the journal La Medicina del Lavoro published an article by F. Tomasina et al. titled Audiometric Database of Academic Musicians in Uruguay [45], which concludes that orchestra musicians, choir singers, and opera soloists experience greater hearing loss than the populations defined by ISO standards. The findings by Tomasina et al. are not comparable to ours for several reasons. The decrease in hearing threshold is only assessed at frequencies of 2000 and 4000 Hz and does not evaluate other important frequencies, particularly 3000 Hz, which is crucial for estimating the progression of noise-induced hearing loss. It is calculated by averaging the hearing thresholds of both ears, whereas in our study, we considered each ear separately because, based on literature and our environmental

measurements, asymmetrical exposure—such as with violins and violas—is common. Additionally, their comparison does not consider damage expected from similar levels of industrial noise exposure. Furthermore, Tomasina's study characterizes the population with heterogeneous exposure, including orchestra musicians, symphonic band members, choir singers, opera soloists, and students. The exposure was also measured as Leq rather than as a weekly exposure estimate, which fails to account for variations in repertoire and exposure duration.

To contribute effectively to knowledge about hearing risks among musicians in opera and symphony orchestras and to propose preventive strategies, researchers must agree on methods to assess exposure, conduct investigations, and evaluate damage.

In this regard, additional studies that better define and identify hearing subjectivity are needed to explore the importance of disorders like tinnitus, hyperacusis, sound distortions, diplacusis, and the sensation of occlusion, which can cause specific "occupational" damage in this group.

5. Conclusion

Our study, in agreement with the majority of studies in the literature, confirms that opera orchestra musicians, although exposed to high noise levels, mostly with Lex-w above 87 dB(A), show a slightly higher risk of hearing damage than the general population, occupationally not exposed to noise, and a significantly lower risk than workers exposed to occupational noise of similar intensity and duration.

It is suggestive that among musicians, who do not usually use hearing protectors, cases of hearing loss are found almost exclusively related to occupational exposure above 87 dB(A).

The longitudinal analysis, comparing audiograms taken more than 10 years apart, shows a progression of hearing loss compatible with physiological ageing.

The high levels of noise impact and related auditory symptoms reported by musicians during rehearsals and performances, and the finding of some cases of hearing loss, however, call for risk reduction interventions:

- Information and training, compulsory under DL 81/2008, emphasizing the relationship between work activity and hearing damage, raising awareness of the use of hearing protectors, particularly during personal practice and rehearsals. In particular, it is of fundamental importance to protect violinists against acoustic trauma in the left ear.
- Exposure reduction should be implemented not through questionable interventions, such as screens and panels (difficult to accommodate in the often-cramped spaces of rehearsal rooms and orchestra pits, which reflect sound and can interfere with musicians' acoustic perception), but by designing the acoustic 'qualification' of spaces. Particular attention must be paid to rehearsal rooms for the containment of sound levels through adequate space for the number of musicians, reduction of sound wave reflections caused mainly by flat walls, and reduction of reverberation through the use of suitable sound-absorbing materials.
- Supplying earplugs, proposing those that are most comfortable and least interfering with musical performance to be used mainly while studying or in some rehearsals.
- Preventive and periodic health surveillance to be carried out with medical examinations and audiological examinations, also in cooperation with audiological specialists as set out in the Guidelines for the Music Sector[6]. It is essential to provide first checks since the beginning of the instrument's study in Conservatories and Academies and to carry out audiological assessments upon employment in orchestras. Subsequent audiological evaluations should be carried out periodically, with more frequent assessment in the first years of activity. To plan a widespread and coordinated prevention activity, it is desirable to discuss the Lyric and Symphonic Foundations, the Lyric Theaters, the Academies, the Philharmonics, the Conservatoires, and other Higher Arts and Music Education (AFAM).

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