PREVALENCE OF HEARING LOSS AMONG UNIVERSITY MUSIC STUDENTS

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Résumé

Cette étude a examiné la sensibilité auditive d'étudiants musiciens (N = 53) et non musiciens (N = 54) âgés entre 17 et 31 ans. Les deux groupes ont été comparés pour les différences de seuil auditif, les incidences de la perte auditive décrite par la moyenne des sons purs, et les incidences d'encoches neurosensorielles à 3, 4 ou 6 kHz. Les données ont également été utilisées pour explorer les relations entre la sensibilité auditive et l'âge, le sexe, l'âge du début des cours de musique, les instruments de musique joués, le nombre d'années jouant cet instrument, le type d'instrument, l'utilisation de protection auditive et le temps d'écoute d'appareils de musique personnelle. Aucune différence significative dans les niveaux de seuil auditif entre les deux groupes n'a été trouvée. La prévalence globale d'encoches neurosensorielles était de 1,9% pour les musiciens contre 9,3% pour les non-musiciens utilisant l'algorithme Niskar (2001), et de 20,8% pour les musiciens contre 31,5% pour les non musiciens utilisant l'algorithme de Coles (2000). Les deux algorithmes ont identifié plus de non musiciens avec des encoches, bien que la différence entre les deux groupes ne soit pas significative. Les musiciens qui utilisent la protection auditive ont beaucoup plus d'encoches neurosensorielles, et il y a eu une faible corrélation entre la sensibilité auditive et l'âge. Les autres paramètres étudiés ont montré très peu ou pas de relation avec la sensibilité auditive. Les résultats ne montrent aucune augmentation de l'incidence de la perte d'audition chez les étudiants universitaires en musique par rapport à un groupe témoin. Cependant, cela ne signifie pas que les étudiants en musique ne sont pas à risque de subir une perte auditive. Il est possible que les outils de mesure que nous avons utilisés ne soient pas suffisamment sensibles pour détecter les premiers stades de la perte auditive ou que l'effet de l'exposition au jeu d'instruments de musique se manifestera quelques années plus tard.

Mots clefs : Musiciens et perte auditive, seuil auditif, bruit causant une perte auditive, étudiants en musique

Abstract

This study examined the hearing sensitivity of university music students (N = 53) and a control group (N = 54) between the ages of 17 and 31. The two groups were compared for differences in hearing threshold levels, incidence of hearing loss described by pure-tone average levels, and incidences of notches at 3, 4 or 6 kHz. Survey data were also used to explore relationships between hearing sensitivity and gender, age, music lesson starting age, musical instruments played, number of years playing that instrument, instrument type, use of hearing protection and personal music device listening time. No significant differences in hearing threshold levels between the two groups was found. Overall prevalence of notches was 1.9% for music students versus 9.3% for the control group using the Niskar (2001) algorithm, or 20.8% for music students versus 31.5% for controls using the Coles (2000) algorithm. Both algorithms identified more controls with notches, although the difference between the two groups was not significant. Music students who use hearing protection had significantly more incidences of notches, and there was a weak correlation found between hearing sensitivity and age. The other survey parameters studied showed very little or no relationship with hearing sensitivity. The results do not show any increased incidence of hearing loss among university music students as compared to a control group. However this does not imply that music students are not at risk of hearing loss. It is possible that the measurement tools were not sufficiently sensitive to detect early stages of hearing loss or that the effect of the exposure to music instrument playing will manifest itself a few years later.

Keywords: musicians hearing loss, hearing threshold levels, noise induce hearing loss, music students

1 Introduction

Professional musicians are often dependent on having and maintaining good hearing health to be successful in their line of work. As such, hearing loss can threaten a musician's ability to perform well and can have a detrimental effect on their career. Hearing loss worries many musicians; when members from five major classical orchestras in Finland were surveyed, 94% expressed concerned for their hearing [1]. We are seeing a growing concern about hearing impairment due to music exposure among musicians, but also among music students and music teachers [2, 3].

It is quite possible that the very act of working as a musician causes irreparable damage to hearing because of

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repetitive exposure to high sound level. Noise-induced hearing loss (NIHL) is usually caused by repeated exposure to high intensity sounds over a period of time and it can affect individuals of all age including young adults [4, 5].

It is generally accepted that 80 dB(A) is the criterion for the maximum sound level that workers can be exposed to without increasing their risk of hearing loss; exposure to sound above this level over an extended period can cause permanent damage [6]. The American National Institute for Occupational Safety and Health [7] and the Canadian Centre for Occupational Health and Safety [8] recommend no more than eight-hours' exposure at 85dB(A) and they suggest that for every increase of three dB, the time limit for exposure be reduced by half [9]. Sound exposure measurements in musicians have confirmed levels over 85 dBA, either in the sound level produced by specific musical instruments or by the orchestra [10-16]. These studies have concluded that musicians are at risk for hearing loss due to the potentially noxious levels of sound exposure present in their working environment. However, according to Schmidt and colleagues [6], it may not be appropriate to apply industrial norms to a musician's environment. A factory worker is exposed to a constant high level of sound over many consecutive hours while musicians are only exposed to high level of sound for short peak periods with quieter moment in between. In addition, contrary to factory workers, musicians are exposed to sound spectra where lower frequencies dominate and these frequencies are less damaging to the ear. One should be cautious about drawing conclusions with respect to hearing loss from these studies, as they do not directly measure hearing threshold levels or incidence of hearing loss. Moreover, when measuring sound levels in a musician's environment, factors such as frequency and duration of rehearsals, type of acoustics in the rehearsal hall or practice studio, number of players in ensembles, number of performances, and type or genre of repertoire should be taken into consideration. These factors vary greatly from day to day and do not comply easily with consistent measurements. For example, musicians do not always practise or rehearse music that produces high levels of noise exposure; Westmore and Eversdeen [17] state there is no risk of hearing loss when playing a Mozart symphony while there may be some risk attached to playing a Bruckner symphony. We agree with Schmidt and colleagues [18] that the intermittent and fluctuating nature of musicians' exposure to various sound levels may be less harmful than continuous noise exposure of a factory or an industry non-fluctuating sound exposure. Thus there will always be uncertainty about whether sound level measurements are representative of what musicians are actually exposed to on a regular basis.

Another approach to determine musicians' risk of hearing loss is to perform hearing tests to determine hearing threshold levels and incidence of hearing loss. Noise-induced hearing loss (NIHL) or hearing loss from long-term noise exposure is often identified by a specific audiometric configuration or 'notch' in the 3 to 6 kHz region [5, 19]. Axelsson and Lindgren [20] conducted one of the early studies on NIHL in musicians and concluded that exposure to classical music in an orchestra on stage or in an orchestra pit can cause auditory trauma. Of the 139 musicians tested, 43% were found to have pure-tone thresholds outside the normal range for their age as determined by Spoor [21] who investigated the effect of aging (presbycusis values) in relation to noise-induced hearing loss. The authors attributed the hearing loss to musical exposure since they could not explain it by other factors from participant histories, including hereditary hearing loss, military service, ear disease or aging hearing loss. Other studies [4, 17, 22, 23] investigating hearing loss in musicians reached similar conclusions, indicating that performing as a professional musician may increase the risk of individual hearing loss. This situation is not limited to classical musicians. Kähäri and colleagues [24] assessed 136 rock and jazz musicians and, according to the study's definition of hearing loss and hearing disorders, found that 49% had hearing loss and 74% had self-reported hearing-related symptoms. Halevi-Katz and colleagues [25] studied professional pop, rock and jazz musicians and also found a positive correlation between the extent of the exposure to amplified music and hearing thresholds of 3-6 kHz; the more exposure musicians had, the poorer their hearing thresholds.

However, methodological limitations in these studies raise questions about the validity of their conclusions. One common limitation is the absence of a control group [22]. Some studies address this issue by comparing their results with pre-existing data sets from other studies [4, 20, 23]. Often, the group of musicians is compared with the data from the International Organisation for Standardization (ISO) that reports the mean numbers for a population of ontologically normal individuals, with age- and sex-corrected hearing thresholds. Some researchers [18, 24] have raised the possibility that the ISO corrections still have some confounding effect for age and could influence the results when musicians are compared to this data. Others suggest that the hearing of the general population, especially for men, has improved since the last update of ISO7029 [26]. In many cases, it is difficult to make definitive conclusions among the different studies due to inconsistencies in how hearing loss is defined (see Appendix A), and/or potentially varying testing conditions and equipment. Another common methodological problem relates to demographic characteristics of the musicians being studied. Quite often, little homogeneity exists within the sample group with regards to age (see Appendix A), number of years of playing, type of music played or musical instrument played. The variance between groups for these demographic characteristics makes it difficult to attribute noise-induced hearing loss solely to music exposure. This is particularly problematic for age differences as presbycusis can deteriorate hearing acuity independent of noise exposure.

To further add to the ambiguity of hearing-loss risk level, several studies provide conflicting evidence to the research presented above, concluding that hearing loss in musicians cannot be attributed solely to the profession. In fact, an early study by Arnold and Miskolczy-Fodor [27] reported that a group of 30 professional pianists was found to have unusually good hearing as compared to the general population. Studies with orchestral musicians have made similar conclusions. Karlsson, Lundquist, and Olaussen [28] demonstrated in a study with 417 orchestra members that performing in a symphonic orchestra does not involve an increased risk of hearing damage. Kähäri, Axelsson, Hellström and Zachau [29] evaluated 140 classical orchestral musicians and found no significant hearing losses that could be attributed to exposure to musical noise. This was further corroborated by the same authors in a follow-up study [30].They examined the hearing threshold of 56 musicians 16 years later and found that there was no sign of any progressive hearing loss except the expected loss related to age. Similar findings were observed in a follow-up study of 123 classical musicians in which no increased hearing damage was observed over a 6-year period [28]. Schmidt and colleagues [18] also reported that the hearing loss of musicians was smaller than the noise-induced permanent threshold shift of the general population. In fact, most of the 394 orchestra musicians that they tested had better hearing at 3, 4 and 6 kHz than expected. Several other studies [28, 31-34, 35] concur that musicians have no increased risk of hearing loss. This situation is not limited to classical musicians, as a review of previous studies reporting on rock and jazz musicians has also found that these musicians had nearly unaffected hearing in a large number of cases in spite of long exposure times to high sound levels [36]. In a study with college students in a jazz-band program, Gopal and colleagues [37] found that all but one experimental subject had normal hearing. While they did find a temporary threshold shift at 4000 Hz after exposure to jazz ensemble-based activity, the mean pure-tone thresholds for right and left ears at 4 kHz were better for the musician group compared to the control group. While these studies arrive at different conclusions than the ones presented earlier, they share similar methodological limitations: the majority have no control group to support their conclusions and sample populations show little homogeneity (see Appendix A).

Hearing acuity is of utmost importance to musicians who depend on their hearing for their profession; therefore, it is vital to understand the risk of hearing loss caused by the music they create and understand the extent to which it is a problem requiring serious consideration. The summary in Appendix A shows that the reported percentage of noise-induced hearing losses in which there was no known cause other than music ranged from 16 to 52.5%; at the same time, a number of studies found no indication of hearing loss due to music exposure. The age of participants ranged between 11 and 70 years and many studies failed to account for the effect of age on hearing loss. Neither the definition of hearing loss nor the criteria used for a noise-induced hearing loss were the same for all studies so the approaches and the results are not consistent. These conflicting results combined with the limitations present in the current literature on hearing loss in musicians justifies the need for further study examining the prevalence of noise-induced hearing loss in musicians when compared to a control group. Therefore, this study will address the following questions:

1. Is there a difference between music and non-music university students in:
    a. hearing threshold levels
    b. incidence of hearing loss
    c. incidence of noise-induced hearing loss (referred to as a notch)?
2. Is there a relationship between hearing sensitivity and the following factors in student musicians: gender, age, starting age for music lessons, musical instruments played, number of years playing that instrument, use of hearing protection and personal music device listening time?

An examination of current literature shows that young musicians have been neglected as a population, with young adult musicians rarely participating in research studies [5, 6]. Little is known about the hearing of university music students and on the damage that their music studies might cause. It has been established that most musicians only start using hearing protection devices once symptoms appear, and tend to neglect them during individual rehearsals [1]. This would indicate that if musicians are indeed at risk, they might not be conscious enough about their hearing health until damage has occurred. The absence of studies focusing on young adult musicians provided the impetus to choose university students as the sample population when comparing hearing loss between musicians and controls.

2 Methodology

2.1 Participants

For the music group, only individuals who had played more than 7 years in the classical tradition were selected. All music students considered for this study had practised seriously over a number of years, enough to be successful in the university audition and show that they had reach the minimum performance level to be admitted into a university music program. All participants in the music group had completed or were in the process of completing an undergraduate music program. The number of hours of actual practice and rehearsal time at the time of the testing was not retained as a selection criterion. We believe that this information is less reliable than the number of years a participant had been playing their instrument and the level they had attained to be admitted into a university music program. For example, at the time of the testing, some graduate students were no longer in a performance program but were engaged in thesis research. Their amount of daily practice had diminished, but all of them had initially been admitted into an undergraduate music performance program and had met the audition requirements and a minimum of seven years of practice on their instrument. Hearing sensitivity is not something that improves once you stop being exposed to certain noise levels (i.e. stop practicing your instrument); the damage done is permanent, so it was more important to consider the number of years of practice and the performance level reached, than the amount of practice at the time of the testing.

While we recognize that singers, like other instrumentalists, may be at risk of hearing loss [38], vocalists were not retained for this study because of the many differences between singers and instrumentalists. Singers usually start their training late; many university students in voice had been training for less than 5 years, therefore were not comparable with our instrumental participants. Additional concerns were with respect to practice time (most vocal instructors in our institution recommend 2 hours or less of daily practice to protect their voice, while most instrumental instructors recommend more than 3 to 5 hours of daily practice), and the inherent difference in the way the sound is produced (internal versus external instrument).

The control group was made up of university students of the same age group who are not involved in a university music program. Any individual who had played a musical instrument for 5 years or more was not retained for this study.

Participants were recruited by advertising free audiology evaluations offered by the “Clinique universitaire interprofessionnelle en soins de santé primaires” [Interprofessional University Clinic in Primary Health Care] from the Faculty of Health Sciences at the University of Ottawa. These advertisements were posted within the University of Ottawa School of Music, Faculty of Social Sciences and Faculty of Engineering. Participants who registered for hearing evaluations were asked if they would be willing to participate in a research project and agree to have the Clinic provide us with their test results anonymously. Interested participants signed consent forms and then completed the demographic questionnaire, which asked questions about gender, age, current academic program and use of hearing protection and personal music device listening time. Participants also had to complete a questionnaire on their music background. Students for the control group were asked if they had learned a music instrument in the past and for how long. Music students had to provide information regarding the age at which they started music lessons, musical instruments played, number of years playing that instrument, practice and rehearsal time and use of hearing protection.

In order to have groups of participants that were similar in age, only individuals between the age of 17 and 31 were considered for participation in this study—this range reflects the typical age of university undergraduate and graduate students.

Table 1 shows the number of participants recruited and the number of participants retained for this study.

Table 1: Recruitment statistics, including potential participants who were removed because they did not meet the experiment group criteria.

Participant recruitment	Control	Music Students	Total
Total recruited	81	72	153
Removed (Age > 31)	1	7	8
Removed (Vocalist)		6	6
Removed (Played instrument < 7 years)		6	6
Removed (Played instrument ≥ 5 years)	26		26
Total used in analysis	**54**	**53**	**107**

The 53 music students consisted of 30 females and 23 males. Their mean age was 22.5 years (range: 17 to 31, *SD* = 3.1). All were trained in classical music and were registered in the following programs: Bachelor of Music (*n* = 23), Master of Music (*n* = 17), Master of Arts in Music (*n* = 9), Honours bachelors with specialization in music (*n* = 3), recently completed an undergrad music program and now working as a musician (*n*=1). The primary instruments were as follows: 19 pianists, 10 string players, 15 brass and wind players, 7 guitarists, 1 percussionist and 1 harpist. The mean number of years practicing their instrument was 14.6 (range: 7 to 26, *SD* = 4.7). Seven participants also indicated that they were exposed to other type of musical sources and identify those as ‘loud sound’: a military band, a band, a rock group, a music group and gigs (various unspecified venues). This was taken into consideration in the analysis and is discussed in the results section.

The 54 participants in the control group were made up primarily of engineering and psychology students (because of where the project was promoted). There were 36 females and 18 males, with mean age of 23.0 years (range: 18 to 30, *SD* = 2.5). Among this group of non-music students 22 had played an instrument in the past. The mean number of years playing an instrument was 2.1 (range: 0 to 4, *SD* = 1.0).

2.2 Procedure

Participants underwent an otoscopic and audiometric evaluation. Otoscopy ensured the ear canal was clear of debris or wax that might interfere with testing, and audiometry (Kamplex AD-25; Madsen Midimate 602; Midimate 603; Madsen AC40) involved measuring hearing thresholds between 250 to 8000 Hz.

2.3 Data analysis

A statistical analysis (Statistical Package for Social Sciences) and Microsoft Excel were used for the data analysis. All *p*-values are two-tailed and considered significant below the 0.05 level. The data analysis was completed as follows:

Hearing loss

a. Hearing threshold levels: the difference in median hearing threshold levels was compared for the two groups using the Mann-Whitney U test. To check for asymmetrical hearing loss, hearing thresholds levels between each ear were compared using the Wilcoxon signed-rank test. Non-parametric tests were used for these analyses because the hearing threshold levels were distributed non-normally.
b. Incidence of hearing loss: the differences in incidence of hearing losses, based on pure-tone average (PTA) threshold levels were compared. As shown in Table 2, each participant was categorized according to degree of hearing loss as described by Clark [39]. Fisher’s exact test was used to compare the number of participants in each group for each hearing loss level.

Table 2: Classification of degree of hearing loss calculated from the pure-tone average (PTA) thresholds

	PTA threshold range (dB)
None	≤15
Slight	16 to 25
Mild	26 to 40
Moderate to profound	≥41

c. Incidence of noise-induced hearing loss: the audiometric notch was used as an indication of noise-induced hearing loss since according to Feuerstein and Chasin [19], in contrast to acoustic trauma, hearing loss from long-term noise or music exposure is typically in the 3 to 6 kHz region. There is very little agreement about a standard definition of a notched audiogram [40], therefore notches were identified using two algorithms commonly adopted to be sure that the results were not merely a factor of the notch definition used. The first definition used was outlined in Niskar and colleagues [41] in which the audiogram must meet all of the following three criteria for at least one ear: (1) threshold values at .5 and 1 kHz were ≤ 15 dB, (2) the maximum threshold value at 3, 4, or 6 kHz was at least 15 dB higher than the highest threshold value for .5 and 1 kHz and (3) the threshold value at 8 kHz had to be at least 10 dB lower than the maximum threshold for 3, 4, or 6 kHz. The second algorithm used is from Coles, Lutman, and Buffin [42] in which the threshold at 3, 4 or 6 kHz is at least 10 dB greater than that at 1 or 2 kHz and at 6 or 8 kHz. After identifying notches using the above definitions, Fisher's exact test was used to compare the number of participants in each group with an audiometric notch. Finally, notches were categorized according to their frequencies, and in which ear they occur.

Factors possibly affecting music students' hearing sensitivity

The relationship between music students' hearing sensitivity and gender, age, music lesson starting age, number of years playing, musical instruments played, use of hearing protection and personal music device listening time were analyzed. For these analyses, the high frequency pure-tone averages (HFPTA) and/or incidences of notches were used as they are indicative of noise-induced hearing loss [19].

3 Results

3.1 Hearing loss

Hearing threshold levels

The Mann-Whitney U test was used to compare hearing threshold levels between music students and control. Figures 1 and 2 show the median threshold levels at each frequency tested for the left and right ears. There were no significant differences between the two groups at any frequency level, although a slight trend favouring the control group is evident. Of the 16 comparisons (8 frequency levels for each ear), music students' median thresholds were slightly higher for five measurement frequencies, while the non-music students' median threshold was higher at just one frequency level (8kHz in the right ear). The median thresholds were equal for the remaining ten measured frequencies.

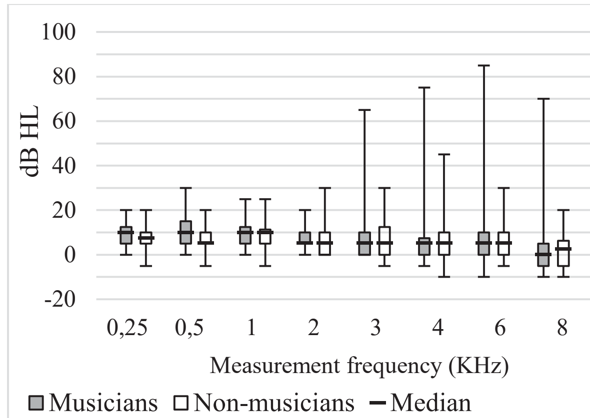

Figure 1: Comparison of hearing threshold levels (dB) for each measurement frequency in right ear. Boxes represent the range from 1st to 3rd quartile and the lines represent range from minimum to maximum. No significant differences were found between music students and control.

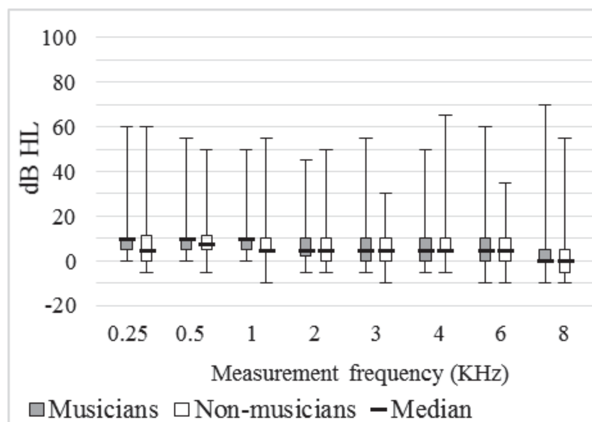

Figure 2: Comparison of hearing threshold levels (dB) for each measurement frequency in right ear. Boxes represent the range from 1st to 3rd quartile and the lines represent range from minimum to maximum. No significant differences were found between music students and control.

For both groups, hearing threshold asymmetry was investigated. The Wilcoxon signed-rank test showed no significant differences in hearing threshold levels between the right and left ears.

Incidence of hearing loss

Incidence of hearing loss using pure-tone average thresholds were analyzed for differences between music students and control Pure-tone average thresholds were calculated for each ear at the following frequencies: 500, 1000, and 2000 Hz, the frequencies usually considered for this purpose [19].

Each participant was then classified by his/her degree of hearing loss. Fisher's exact test was used to compare incidence of hearing loss for each hearing loss level. Table 3 shows that six music students and three controls exhibited signs of hearing loss; however, no significant differences were found in the prevalence of hearing loss between music students and controls.

Table 3: Incidence of hearing loss using the pure-tone average thresholds for three frequencies: 500, 1000, and 2000 Hz. Number and percentage (in parenthesis) of participants are shown.

Degree of Hearing Loss	Music Students	Control	*p*-values
No hearing loss (0-15 dB)	47 (88.7%)	51 (94.4%)	.32
Slight hearing loss (16-25 dB)	4 (7.5%)	2 (3.7%)	.44
Mild hearing loss (26-40 dB)	1 (1.9%)	0 (0.0%)	.50
Moderate or severe hearing loss (> 40 dB)	1 (1.9%)	1 (1.9%)	1.00
Total with hearing loss (> 15 dB)	6 (11.3%)	3 (5.6%)	.32

A second similar test compared high frequency pure-tone averages (HFPTA) for 3000, 4000 and 6000 Hz between music students and control. This was included to give an indication of noise-induced hearing loss, which more commonly appears at higher frequency levels. Table 4 shows that three music students and five of the non-music students had some degree of hearing loss. Again, no significant differences were found for incidence of hearing loss between music students and control at any hearing loss level.

Table 4: Incidence of hearing loss using the pure-tone average thresholds for three frequencies: 3000, 4000, and 6000 Hz. Number and proportion (in parenthesis) of participants are shown.

Degree of Hearing Loss	Music Students	Control	*p*-values
No hearing loss (0-15 dB)	50 (94.3%)	49 (90.7%)	.72
Slight hearing loss (16-25 dB)	1 (1.9%)	3 (5.6%)	.62
Mild hearing loss (26-40 dB)	0 (0.0%)	1 (1.9%)	1.00
Moderate or severe hearing loss (> 40 dB)	2 (3.8%)	1 (1.9%)	.62
Total with hearing loss (> 15 dB)	3 (5.7%)	5 (9.3%)	.72

Incidence of noise-induced hearing loss (notches)

The incidences of notches were analyzed to compare for differences between music students and control. Two algorithms were used to determine the presence of a notch, as described above. Using the first algorithm from Niskar and colleagues [41], only one of the 53 music students had a notch, while five of the 54 non-music students had a notch in one or both ears. Fisher's exact test was used to evaluate for differences between incidences of notches between music students and control. While there is a noticeable higher incidences of notches among the control participants, no significant differences were found, $\chi2$ (1, n = 107) = 2.747, p = .10. The second algorithm from Coles and colleagues [42] identified more notches, again with more among the control participants (17 participants with notches in one or both ears, compared to 11 music students) but no significant difference between the two groups: $\chi2$ (1, n = 107) = 1.593, p = .21.

The notches were also tabulated according to the frequency at which they occur. Table 5a and 5b show the distribution of notches found using each algorithm. Notches were found at each of the three frequencies, although they are slightly more prevalent at 3000 Hz.

Table 5a: Incidences of Notches According to Frequency using Algorithm 1

	Notch location (Hz)		
	3000	4000	6000
Music students			
Unilateral (right ear)			
Unilateral (left ear)			1
Bilateral			
Musician total			**1**
Control			
Unilateral (right ear)	1	1	1
Unilateral (left ear)			1
Bilateral	2		
Control total	**3**	**1**	**2**

Table 5b: Incidences of Notches According to Frequency using Algorithm 2

	Notch location (Hz)		
	3000	4000	6000
Music students			
Unilateral (right ear)	1	1	3
Unilateral (left ear)	2	1	1
Bilateral	2	2	
Music student total	**5**	**4**	**4**
Control			
Unilateral (right ear)	3	1	2
Unilateral (left ear)	1	4	1
Bilateral	5	1	4
Control total	**9**	**6**	**7**

3.2 Factors possibly affecting hearing sensitivity

Gender

Among music students, there were 30 females and 23 males, and among controls, there were 36 females and 18 males. The median HFPTA was compared for males and females within each group using the Mann-Whitney U test. Pure-tone average for the higher frequencies (3 to 6 kHz) was used for this analysis (and the others that follow) as this is indicative of noise-induced hearing loss [19]. There was no significant difference in hearing sensitivity between males and females for either group. For music students: Md (females) = 6.67, Md (males) = 6.67, U = 344, z = -0.027,

$p = .98$. For controls: *Md* (females) = 7.50, *Md* (males) = 5.0, $U = 290$, $z = -.64$, $p = .52$.

Age

The correlation between age and the hearing threshold level for each group was investigated using HFPTA. The age distribution for each group was similar: the mean age for music students was 22.5 years (range: 17 to 31, $SD = 3.1$), and the mean age for controls was 23.0 years (range: 18 to 30, $SD = 2.5$). For both groups there was a weak correlation between the two parameters, with hearing thresholds worsening slightly with increased age; however the results were non-significant for both groups. For music students, $r = .26$, $n = 53$, $p = .06$. For controls, $r = .16$, $n = 54$, $p = .26$.

Music lesson starting age

Within the musician group only, the effect of music lesson starting age was explored. The music students' age at the start of music lessons ranged from 3 to 14 years ($M = 8.7$). No correlation was found between HFPTA and starting age ($r = 0$, $n = 52$, $p = .99$).

Year of playing

The number of years that the musician participants have been playing their instrument ranged from 7 to 26 (M = 14.6). A partial correlation (controlling for participant age) showed no relation between years of playing and HFPTA threshold: $r = 0$, $n = 51$, $p = .96$. Furthermore, those with more years of playing had fewer incidences of notches (using the Coles [42] algorithm): only two of the eleven notches were identified for participants with 15 to 26 years of playing experience.

Musical instrument

The impact of instrument type on hearing sensitivity was examined by grouping the instruments into the following categories: brass ($n = 6$), guitar ($n = 7$), piano ($n = 19$), strings ($n = 10$), wind ($n = 9$) and other ($n = 2$). A Kruskal-Wallis test revealed no significant differences in HFPTA threshold levels and instrument played: $\chi2$ (5, $n = 54$) = 1.02, $p = .91$.

Difference in hearing between left and right ear was investigated for those instruments that have been shown to potentially cause asymmetrical hearing loss [6]. The mean HFPTA between the right and left ears, and the incidences of notches for each ear were compared. The notches used for this analysis were only those identified by the Coles and colleagues [42] algorithm, as there was only one notch for musician participants identified using the other method. The results in Table 6 show only a small difference in threshold levels between the ears, although one unilateral notch was found for each instrument of interest. While conclusions are not possible due to the small numbers of participants for each of those instruments, it can be observed that the unilateral notch appears in the ear that would be expected: right ear for flute and French horn [20], and left ear for violin [23, 43]. The number of participants for each instrument is not sufficient for a statistical analysis to confirm the significance of these results.

Table 6: Comparison of right and left ear pure-tone average threshold levels and incidences of notches using the Coles et al. (2000) Notch definition.

		Mean HFPTA (dB)		Participants with Notches		
	#	RE	LE	RE	LE	Bilateral
Flute	4	7.5	5.0	1		1
French Horn	2	0.0	4.2	1		
Violin	8	6.0	7.7		1	
Other	39	6.8	6.2	3	3	1

Use of hearing protection

A majority (42 out of 53) of musician participants did not use hearing protection. Ten responded that they either use hearing protection, or sometimes do, and one participant did not answer the survey question. The ten participants who use hearing protection play the following instruments: flute ($n = 3$), guitar ($n = 3$), violin ($n = 2$), percussion ($n = 1$) and trumpet ($n = 1$).

To compare the hearing of the participants who use hearing protection and those who do not, the difference in hearing threshold levels and incidences of notches as identified by the Coles and colleagues [42] algorithm were investigated. The Mann-Whitney U test showed no difference in HFPTA between those who use hearing protection (*Md* = 8.3, $n = 10$) and those who do not (*Md* = 5.0, $n = 42$), $U = 176$, $z = -0.81$, $p = .42$. However, Fisher's Exact test indicated a significant difference in incidences of notches among participants who use hearing protection (5 out of 10, or 50%) compared to those who do not (6 out of 42, or 14%), $\chi2$ (1, $n = 52$) = 6.12, $p = 0.01$. This finding was not confounded by age or years of playing; the mean of these parameters for those who use hearing protection and have notches was very close to the mean values of those with no notches.

Personal music device listening time

The participants indicated the amount of time per day spent listening to personal music devices with headphones. Listening time for both groups ranged from 0 to 5 hours; however, the Mann-Whitney U test showed controls' listening time (*Md* = 1.5, $n = 49$) to be significantly higher than that of music students (*Md* = 1.0, $n = 53$), $U = 839$, $z = -3.11$, $p = .002$.

The effect of music device listening time on HFPTA was explored using a Pearson product-moment correlation coefficient. A weak positive correlation was found for the music students ($r = .22$, $n = 51$, $p = .08$), and no correlation was found for controls ($r = -.06$, $n = 46$, $p = .75$).

The effect of music device listening time on incidences of notches was explored by comparing listening time of those with notches compared with listening time of those without. For both music students and controls, the Mann-

Whitney U test showed no relation between these two parameters (music students with notch: $Md = 1.0$, $n = 11$, no notch: $Md = 1.0$, $n = 42$, $U = 221$, $z = -.22$, $p = .82$, and controls with notch: $Md = 1.5$, $n = 15$, no notch: $Md = 1.5$, $n = 34$, $U = 355$, $z = -.45$, $p = .65$).

Exposure to loud noise

Participants were asked "Are you regularly exposed to loud sound?" and if so, to explain. 43% of the music students (23 out of 53) responded that they are exposed to loud noise. In most cases, the loud noise they referred to was that of their instrument and/or exposure to other instruments while performing in a group. Seven of the responses referred to noise other than that of the practice or performance of classical music. Those seven cases included other types of music performance (e.g. rock music, military band rehearsal) and other noise such as bars and audio production. Eight of the 54 controls (15%) responded that they are exposed to loud noise, referring to bars, clubs, crying children and machine operation.

The effect of the reported exposure to loud noise (not including that of classical music practice/performance) on hearing sensitivity was examined using incidences of notches and HFPTA levels. There was no effect of exposure to loud sound on incidences of notches for both music students and controls (just two of the 11 notches in music students and one of the 17 notches in controls were found in those exposed to loud noise). The Mann-Whitney U test showed no effect on the HFPTA for the controls exposed to loud sound (those exposed to loud sound ($Md = 7.50$, $n = 8$) compared with those not exposed ($Md = 9.06$, $n = 46$), $U = 183$, $z = -.04$, $p = .97$). For music students there was an effect on HFPTA where those exposed to loud sound not related to the practice and/or performance of classical music ($Md = 10$, $n = 7$) had higher a HFPTA compared to those not exposed ($Md = 5$, $n = 46$), $U = 66$, $z = -2.53$, $p = .01$).

4 Discussion

The objective of the present study was to assess the risk of hearing loss for music students by comparing the hearing sensitivity of young adult music students (ages 17 to 31) with a similar group of controls. This was accomplished by comparing hearing threshold levels, incidence of hearing loss as determined by pure-tone threshold levels, and incidence of noise-induced hearing loss as determined by presence of audiometric notches. The results demonstrate no significant differences between music students and controls for all of these hearing sensitivity metrics. These findings are consistent with several other studies that found that musicians do not have increased risk of hearing damage [5, 6, 15, 17, 28-31, 34, 44].

Kähäri and colleagues [24] reviewed different reasons that could explain why musicians, with a long history of sound exposure, do not necessarily show hearing losses. It could be that musical sound exposure has a positive effect that stimulates and activates the stapedial muscle and this could contribute to a toughening effect [45-47]. It could also be that, due to genetic factors, musicians have different susceptibilities to noise-induced hearing disorders [48]. Schmidt and colleagues [18] have also considered the possibility that musicians are less susceptible to noise-induced hearing loss than the general population; they have better hearing and their hearing may degenerate at a slower speed than what would be expected with normal aging.

Nevertheless, a number of other studies found that exposure to classical music in an orchestra can cause auditory trauma [4, 20, 22, 23, 43]. Two common limitations were observed in these studies: the absence of a control group in most studies and little homogeneity within the sample groups. To compensate for these shortcomings, the current study was constructed to measure the hearing acuity difference between music students and controls with similar demographic characteristics. To account for the effect of age on hearing loss, the age ranges in each group were small. Homogeneity within the musician group was ensured in terms of number of years of playing (more than 7 years) and type of music played (trained in the Western classical music tradition). However, a lack of homogeneity in instrument type was unavoidable; inclusion criterion was that a participant should be studying any musical instrument in the classical music tradition. For that reason, we included orchestral musicians, pianists and guitarists.

Regarding the incidences of notches, the findings unexpectedly reveal a noticeable higher incidences of notches among controls; however, no significant differences were found. Schmidt, Verschuure, and Brocaar [6] used a similar notch definition as algorithm 2 in this study, and found a similar proportion of musicians with notches (16% compared to 19% in this study). They also found no differences between musicians and a non-musician control group. However, other studies found much higher proportions of musicians with notches. Using a notch algorithm similar to algorithm 1 in this study, Jansen, Helleman, Dreschler, and de Laat [4] found a 20% notch rate compared with the current study's result of 2%. Using an algorithm similar to algorithm 2 in this study, Royster, Royster, and Killion [43] found a 52.5% notch rate. Both of these studies included older participants (up to ages 64 and 70 respectively), so it is not surprising to see higher incidences of notches. Phillips, Henrich, and Mace [5] studied younger musicians (ages 18 to 32) and found an alarmingly high notch rate of 45%. However, the notch algorithm appears to be modified significantly from the Niskar and colleagues [41] definition, and it is not therefore possible to directly compare the results. Other studies that report incidences of notches do not provide a clear methodology used to identify notches [17, 23]; with no standardized method to identify audiometric notches, it is not possible to directly compare results with these studies.

It should be emphasised that the notches found in the current investigation were distributed almost evenly between frequencies of 3, 4 and 6 kHz. This is in contrast to other studies that found notches among musicians to be more prevalent at 6 kHz. Both Jansen and colleagues [4] and Kähäri and colleagues [29] found notches in the median audiograms at 6 kHz. Phillips and colleagues [5] found that 78% of the notches occurred at 6 kHz. This can be compared with industrial workers who typically have notches at 4 kHz [5]. This suggests the possibility that, in comparison to other studies, a smaller proportion of the notches identified in this study can be attributed to practicing or performing music, and thus some of the noise-induced hearing loss that was identified was likely due to other factors.

A comparison of hearing sensitivity between left and right ears revealed no signs of asymmetrical hearing loss among either group. These results are consistent with studies such as Schmidt and colleagues [6], which found no asymmetrical hearing losses. However, other studies have shown that asymmetrical hearing loss is common, usually with more loss in the left ear [14, 49, 50]. Many studies with musicians have found a link between this asymmetry and the instrument played: larger hearing loss in the left ear were found with violinists [23, 42-44, 51, 52], while larger hearing loss of the right ear was found among flautists [20, 44], French horn players [20] and piccolo players [51]. The current study found that a horn player, violinist and flautist each had an audiometric notch in the expected ear as mentioned above, however the number of participants from each instrument group was not sufficient to draw conclusions from these results.

Unexpectedly, a higher proportion of notches were found among music students who use hearing protection compared to those who do not. It is possible that music students who have noticed some signs of hearing loss would make an effort to protect their hearing, whereas those who think their hearing levels are normal may not feel the need to use hearing protection. This speculation is supported by Laitinen [1] who found that hearing protection was more often used among musicians who have symptoms of hearing loss. Some other studies have reported on usage rate of hearing protection, but none reported audiological evaluation results using hearing protection usages as an independent variable.

Personal music devices can submit users to harmful exposure levels. A recent study by Twardella and colleagues [53] found that in one quarter of those who use such devices, exposure levels exceeded 85 dB(A), the occupational limit in many jurisdictions [7, 8]. Daniel [54] also reported that temporary and permanent hearing problems are more common now that children and teenagers have increased exposure to portable music players. In the current study, there was a weak positive correlation between listening time and HFPTA among music students, but the same trend was not observed in the control group. No relation was found between listening time and incidences of notches for either group. Other studies had similar results. Twardella and colleagues [53] found that high exposure to music from personal devices in adolescents could be considered as a risk factor for developing noise-induced hearing loss; however, prevalence of audiometric notches was not found to be significantly associated with higher personal music device exposure. It is interesting to note that the controls listen to personal music devices more than music students do. It may be surmised that music students, due to the importance of audition to their vocation, are more aware of potential causes of hearing loss, and therefore do not use headphones as much as the general population. Alternatively, there may be other reasons they seek silence when they are away from their instruments. Another study [22] found that more than 50% of musicians avoided noisy environments and sought silence in their leisure time.

Another indication that music students may be more sensitive and aware of sound or noise exposure is their response to the survey question, “Are you regularly exposed to loud sound?” Twenty-three (43%) of the music students responded yes. In comparison, only 8 (15%) of the controls responded yes. Furthermore, most of the controls reported examples of loud sounds were indeed high noise-exposure sources (e.g., bars, machine operation and construction work), whereas many of the musician’s reported examples that would not likely yield such high exposure levels (e.g. piano teaching). This indicates that the music students had a different perception of what could be considered a loud sound.

Gender had no effect on hearing sensitivity. This result was as expected; the International Organization for Standardization 7029 [55] statistical distribution of hearing thresholds as a function of age shows that noticeable differences between males and females do not appear until beyond the age of 30. Phillips and colleagues [5], who also studied younger musicians, found no gender effect.

In our study, several parameters relating specifically to the music students’ music experience were investigated for effects on hearing sensitivity. These included: music lesson starting age years of playing, and musical instrument. No effect on hearing sensitivity was found for these variables. With respect to the impact of instrument type, results found in the literature are inconsistent. Some studies, all of which included older orchestral players, found some differences in hearing, depending on instrument or instrument group (worse hearing in brass players [20, 35], double bass and flute players [28], better hearing in lower string players [4], piano, harp and low string players [43]), but others, including Phillips and colleagues [5] with a young musician population, found that instruments were not significant factors [17, 23, 29, 31]. Schmidt and colleagues [18] report that instrument groups are poor predictors of the hearing thresholds. Effects on hearing for the other parameters we tested for were not reported on in the literature.

5 Limitations and future direction

When interpreting the results of this study, it is important to consider several methodological limitations. Firstly, the students were invited to participate through advertisements; as such, the recruitment process was not random. There exists the possibility that the sample population was not representative of the general population, as it could be biased towards those who had some reason to believe their hearing might be compromised and wanted it tested. Conversely, it could have attracted those who are concerned about hearing loss, but have very good hearing due to their awareness and cautiousness about noise exposure.

Of utmost importance are the audiogram's limits in terms of what it allows us to measure. Although the audiogram is a very important clinical tool, one has to keep in mind that the picture it yields of an individual's hearing is limited in several aspects. First of all, the traditional audiogram measures hearing from 250 Hz to 8 kHz. However, considering human hearing can detect sounds up to 20 kHz, measuring thresholds for higher frequencies (9-20 kHz) provides a more complete picture of one's hearing status. Extended high-frequency audiometry (EHFA) has been shown to be useful in diagnosing hearing loss related to several conditions, among which is noise-related hearing loss [56]. Hence, such a measure would have been relevant for this study. Additionally, off-frequency listening, a phenomenon in which a tone of a particular frequency is detected via inner hair cells (IHCs) and neurons with characteristic frequencies different from that of the tone prevent dead cochlear regions from being revealed through routine audiological evaluations [57]. Consequently, such regions might have been present in some participants, but not have been detected through the traditional audiogram. Similarly, cochlear synapthopathy, which is characterized by dysfunctional IHC/type I auditory-nerve fiber synapses, has been shown to result from noise exposure. Because this dysfunction cannot be detected using traditional audiometry, cochlear synaptopathy is often referred to as noise-induced hidden hearing loss (NIHHL) and might have been existent for some participants [58]. Finally, the audiogram only measures one of the characteristics of sensorineural hearing loss: reduced sensitivity. However, sensorineural hearing loss also leads to reduced frequency selectivity, reduced temporal resolution and abnormal growth of loudness [59]. Another limitation of this study was that otoacoustic emissions (OAEs) were not measured. Given that OAEs are thought to reflect activity of the outer hair cells (OHCs) [60] and that OHCs are generally the first affected in case of sensorineural hearing loss, this measure might have provided valuable additional information.

Pure-tone audiometry might not be a sufficiently sensitive test to detect early stages of hearing loss and it might be preferable to do a full assessment of hearing [24, 29, 61], including the evaluation of hearing disorders other than hearing loss. Kähäri and colleagues [24] suggest that frequent hearing problems are tinnitus, hyperacusis, distortion and/or diplacusis, speech in noise, and uncomfortable loudness level of pure tones. Laitinen and Poulsen [61] state that aspects other than hearing loss must be considered, since the most frequent hearing disorders that affect musicians are tinnitus and hyperacusis.

The experiment design would not be able to show a causal relationship between music performance and hearing loss. Some studies [10-17, 34, 35] use dosimetric measurement to attempt to address this, however we felt that this would not provide reliable data due to the variability in practice and performance environments, especially for student musicians. Furthermore, even if a hearing impaired musician's exposure was found to be high, the hearing loss could be due to other causes. Thus, the nature of this type of experiment is such that it is not possible to conclusively claim that any given musician's hearing loss is due to the practice or performance of their instrument. Nevertheless, in retrospect additional information about the performance environment including sound level data would have been of interest, and future researchers may well find it valuable to use dosimetry in following this line of research.

While we strived to select homogenous experiment groups, there was still some variability that was unavoidable. The exposure of the musician group varied in terms of practice time, years of study, and group performances; these parameters were taken into consideration, however they were not objectively measured. Additionally, we cannot assume that participants were not exposed to other noise unrelated to their instrument, even if they did not mention this in the questionnaire. Finally, we did not have sufficient sample sizes within each instrument type to draw conclusions on an individual instrument basis. Furthermore, in grouping the various instrumentalists together as a musician group there was potential to hide the effect of noise exposure, given the presence of quiet instruments such as flute or guitar. That said, we are confident this was not an issue, as we did not find lower threshold levels for those participants playing quiet instruments. With respect to the control group, participants ideally would have no music experience at all, however we had to allow for some music experience in order to recruit sufficient sample size.

6 Conclusion

Based on current findings, it would seem that young adult musicians do not exhibit a higher incidence of hearing loss than a control group, at least not with the conducted measures. However, it is important to remember that this might be because music students have not yet been affected with a permanent hearing loss. Gopal and colleagues [37], when measuring college students after a 50-minute jazz and band classroom activity, found a significant temporary threshold shift bilaterally at 4000 Hz. This shift in threshold is thought to be temporary in nature, since follow‑up testing did not demonstrate the shift, but it may be that temporary auditory changes seen in these music students could put them at risk for hearing loss in the years to come. It would be important, as a follow-up studies, to conduct a larger experiment with more participants from each instrument group to determine the effect of instrument type on hearing sensitivity, and to test musicians in the next age group (30-40 years old) to find out if these musicians are starting to show sign of hearing loss. A longitudinal study would help find out whether the percentage of noise-induced hearing losses increases with time for these young musicians.

If university music students do not show apparent damage, it might be a good time to educate them about the importance of being careful with exposure to loud noise and teach them how to protect their hearing system. While musicians can protect themselves with hearing protection, they are not always ready to consider earplugs; they may consider that they are uncomfortable and can affect their hearing during performance, particularly with regard to timbre and dynamics [25]. The time to discuss these topics might be while these young musicians are in university.

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Appendix A: Previous Study Parameters and Results

	Authors	Definition of hearing loss or hearing loss criteria	Comparison group	Age	Result	Musician type
Found increase risk of hearing loss	Axelsson and Lindgren, 1981	Threshold level greater than 20 dB on one ear and one frequency	Other study (Spoor, 1967)	20 to 70	43% of musicians showed worse pure-tone thresholds than would be expected with regard to age.	Classical
	Emmerich, Rudel, & Richter, 2008	Permanent threshold shifts larger than 15 dB SPL	None	30 to 69 & 11 to 19	More than 50% of the musicians had a hearing loss of 15dB(A) and more.	Classical
	Jansen, Helleman, Dreschler, & de Laat, 2009	Threshold level > 15 dB at any of the measured frequencies. Notches categorized as moderate or profound	ISO 7029 (2000)	23 to 64	Most musicians could be categorized as normal hearing, but their audiograms show notches at 6 kHz. (11% had moderate notches, 9% had profound notches).	Classical
	Ostri, Eller, Dahlin, & Skylv, 1989	Threshold level ≥ 20 dB at any threshold in one or both ears	ISO 7029 (1984)	22 to 64	58% of the musicians had a hearing impairment. 50% of males and 13% of females showed typical audiogram with notched curve.	Classical
	Kähäri, Zachau, Eklöf, Sandsjö & Möller, 2003	2 or more frequencies at ≥ 25 dB or 1 frequency at ≥ 30 dB in ≥ 1 ear	None	26 to 51	49% of participants with hearing loss	Pop, rock, jazz
	Halevi-Katz, Yaakobi, Putter-Katz, 2015	Threshold shift at 3 to kHz	None	20 to 64	More music exposure was positively linked to higher hearing thresholds in the frequency range of 3-6 kHz	Pop, jazz, rock
Found no increased risk of hearing loss	Karlsson, Lundquist, & Olaussen, 1983	Not indicated	Other study (Spoor, 1967)	20 to 69	Thresholds measured did not differ from the reference values from Spoor (1967)	Classical
	Kähäri, Axelsson, Hellström, & Zachau, 2001a	Not indicated	ISO 7029	23 to 64	HFPTA values in most ears distributed around the ISO 7029 median.	Classical
	Kähäri, Axelsson, Hellström, & Zachau, 2001b	Not indicated	ISO 7029	35 to 64	Most HFPTA values were distributed between the ISO median and within the 90th percentile.	Classical
	Johnson, Sherman, Aldridge, & Lorraine, 1985	Not indicated	Past study (Spoor, 1967)	24 to 64	Musicians did not appear to have hearing remarkably different from normal expectations.	Classical
	Schmidt, Verschuure, & Brocaar, 1994	Presence of dip (hearing loss in one or both ears ≥ 20 dB for 3,4 or 6 dB with the loss at the two nearest frequencies on both sides of the dip amounting to at least 5 dB less), high-frequency and extended high-frequency sensorineural hearing loss, or conductive hearing loss	Study control group (medical students)	21 to 40	Musicians: 16% with noise dips, 20% with high-frequency losses: 72% with extended high-frequency losses. Similar results found in control group.	Classical (*n*=39), light music (*n*=26), pop music (*n*=5), ethnic music (*n*=2), not provided (*n*=7)

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Found no increased risk of hearing loss	Toppila, Koskinen, & Pyykkö, 2011	Not indicated	ISO 1999	43 to 50	The hearing of classical musicians corresponds to that of the non-noise exposed population according to ISO-1999:1990.	Classical
	Gopal, Chesky, Beschoner, Nelson, Stewart, 2013	Not indicated	Non-musician control group	19 to 33	The musician group showed a significant temporary threshold shift bilaterally at 4000 Hz after exposure, however, musician's mean threshold levels pre-exposure were better than that of the control group.	Jazz
	Russo, Behar, Chasin, & Mosher, 2013	Not indicated	ISO 1999	NA	Measured hearing losses for all instrument groups did not approach clinically significant levels, although instrument groups experiencing the highest levels of exposure also had the highest pure-tone thresholds.	Classical
Does not definitively conclude if there is an increased risk of hearing loss	Westmore & Eversden, 1981	Not indicated	None	29 to 60	23 out of 68 ears showed changes consistent with noise-induced hearing loss, but most of those had only slight or early changes. 4 musicians had a hearing loss of more than 20 dB at 4KHz.	Classical
	J. D. Royster, L. H. Royster, & Killion, 1991	Presence of a dip or notch (threshold at 3, 4 and/or 6 kHz being 10 dB or worse than adjacent lower and high frequencies or a dip of 10 dB or more superimposed on a sloping high-frequency-emphasis loss.	ISO 7029 (1984)	30 to 70	Mean hearing threshold levels were only slightly worse than the ISO 7029 median, however 52.5% of musicians showed notched audiograms.	Classical
	Phillips, Heinrich, & Mace, 2010	Presence of a notch 15 dB in depth at 4000 or 6000 Hz relative to the best preceding threshold	None	18 to 32	45% of participants had a notch in at least one ear, however susceptibility to noise-induced hearing loss cannot be ascribed solely to the instrument played and other exposures.	Classical

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