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Tinnitus Severity Is Related to the Sound Exposure of Symphony Orchestra Musicians Independently of Hearing Impairment

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Objectives: Tinnitus can be debilitating and with great impact of musicians professional and private life. The objectives of the study were therefore to: (1) describe the epidemiology of tinnitus including its severity in classical orchestra musicians, (2) investigate the association between tinnitus severity in classical musicians and their cumulative lifetime sound exposure, and (3) the association between tinnitus and hearing thresholds.

Design: The study population included all musicians from five Danish symphony orchestras. Answers regarding their perception of tinnitus were received from 325 musicians, and 212 musicians were also tested with audiometry. Any tinnitus and severe tinnitus were two definitions of tinnitus used as outcomes and analyzed in relation to an estimation of the cumulative lifetime sound exposure from sound measurements and previously validated questionnaires and the average hearing threshold of 3, 4, and 6 kHz.

Results: Thirty-five percentage of all musicians (31% female and 38% of male musicians) reported having experienced at least one episode of tinnitus lasting for more than 5 minutes during their life. Severe tinnitus with a severe impact on daily life was reported by 19% of the musicians (18% of female and 21% of male musicians). The severity of tinnitus was associated with increased lifetime sound exposure but not to poorer high frequency hearing thresholds when the lifetime sound exposure was considered. The odds ratio for an increase in one unit of tinnitus severity was 1.25 (95% CI, 1.12–1.40) for every 1 dB increase in lifetime sound exposure.

Conclusion: Musicians frequently report tinnitus. Any tinnitus and severe tinnitus are significantly associated with the cumulative lifetime sound exposure, which was shown to be the most important factor not only for the prevalence but also for the severity of tinnitus—even in musicians without hearing loss. High-frequency hearing thresholds and tinnitus severity were correlated only if the cumulative lifetime sound exposure was excluded from the analyses.

Key words: Tinnitus, Musicians, Hearing loss, Music, Noise induced.

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INTRODUCTION

Tinnitus is a phantom sensation of sound such as ringing or hissing in the ears without any external sound stimulus. It is a common symptom affecting 10 to 15% of the adult population especially older men (Baguley et al., 2013; Lockwood et al., 2002). In performing classical musicians, an even higher tinnitus prevalence has also been reported from 21 to 51% (Emmerich et al., 2008; Jansen et al., 2009; Laitinen & Poulsen, 2008; Wilson et al., 2013). Furthermore, the incidence rate ratio of musicians suffering from tinnitus was found to be 1.45 compared with nonmusicians in a retrospective cohort of patients with hearing problems, which indicates that tinnitus is a very common symptom among musicians (Schink et al., 2014).

Estimating the prevalence of tinnitus from a self-reported questionnaire is difficult and carries a risk of self-report bias both in musicians and in the general population as demonstrated in a recent systematic review, which found that the overall prevalence of tinnitus ranged from 5.1 to 42.7% depending on the study population and the tinnitus definition that was used (McCormack et al., 2016). An even higher prevalence of tinnitus has recently been reported from a population-based survey, where 59% of the participants have had tinnitus lasting for more than 5 minutes at least at one occasion in the past (Moore et al., 2017). The prevalence of any kind of tinnitus among different populations, for example, Korean, Italian, and U.S. populations, demonstrated variability ranging from 6.2 to 25.3% of the entire population (Gallus et al., 2015; Park et al., 2014; Shargorodsky et al., 2010). Furthermore, experiencing frequent tinnitus, which was defined as at least daily tinnitus in United States and Swedish populations, was reported to occur in 7.9 to 14.2% of the studied populations (Axelsson & Ringdahl, 1989; Shargorodsky et al., 2010). Additionally, the duration of tinnitus that lasted for more than 5 minutes independent of recent sound exposure had a prevalence of 9.7% in a large British study of 48,313 adults (Davis, 1989). This indicates that environmental factors such as noise exposure also affects its prevalence; thus, the rate of tinnitus might be higher if a substantial number of the respondents had been noise exposed at the time point at which the prevalence is estimated. Furthermore, tinnitus prevalence may also be affected by the occurrence of depression or mental disorders as well as genetic differences and differences in diet (McCormack et al., 2015; McCormack et al., 2014; Maas et al., 2017). Another limitation of these studies is that different definitions of tinnitus were used in some of these studies, thereby making direct prevalence rate comparisons difficult. Some studies include the duration of tinnitus for at least 5 minutes, whereas other studies simply measure the prevalence of any tinnitus without any stipulation as to the duration of the symptom. The duration of period of tinnitus largely affects the tinnitus prevalence among musicians and studies indicate that a majority of the musicians have intermittent tinnitus and fewer musicians experience constant tinnitus. For instance, it was demonstrated that 51% of musicians reported tinnitus, while only 17% of the

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musicians had tinnitus present at the time of the investigation (Jansen et al., 2009). Twenty-four percentage of all musicians in a previous Danish study complained of tinnitus lasting more than 5 minutes (Laitinen & Poulsen, 2008). Furthermore, an older Danish study found that only 4% of the musicians had constant tinnitus, while 38% of the musicians experienced tinnitus regularly in relation to a temporary threshold shift following sound exposure (Ostri et al., 1989). Similarly, an Australian study found that 5% of the studied musicians often experienced tinnitus, while 45% of the musicians only occasionally experienced tinnitus (Woolford, 1984). The temporary threshold shift seen following loud sound exposure may very well explain the large differences in the reported tinnitus prevalence rates explaining why many musicians experience tinnitus but fewer notice it constantly (Jansen et al., 2009; Ostri et al., 1989; Woolford, 1984).

It is known that musicians are particularly attentive to the function of their hearing because this sense is vital to match frequencies accurately, a skill that facilitates their ability to play proficiently (Zhao et al., 2010). Therefore, the influence of tinnitus on the quality of life and daily activities may depend on different aspects of such as occupation and mental stress (Engdahl et al., 2012; Krog et al., 2010). For musicians, the symptom can be expected to be perceived as severe, since it may interfere with their occupation as a professional musician and the ability to hear the produced sound perfectly. However, little is known about how tinnitus severity affects the musicians' daily life both when they play music and when they do not. Until now, no studies have investigated the perceived severity of the tinnitus among professional musicians, although some studies indicate that musicians may increase their use of earplugs when they notice tinnitus (Laitinen & Poulsen, 2008; O'Brien et al., 2014). It is therefore possible that tinnitus is associated with noise-induced hearing loss (NIHL) in classical musicians, as NIHL has been reported in several studies (Axelsson & Lindgren, 1981; Emmerich et al., 2008; Jansen et al., 2009; Ostri et al., 1989; Pawlaczyk-Luszczynska et al., 2013; Royster et al., 1991; Schmidt et al., 2014b; Westmore & Eversden, 1981; Wilson et al., 2013). However, studies also found that musicians' hearing thresholds were not worse compared with that of the general population of the same age (Karlsson et al., 1983; Kähäri et al., 2001; McBride et al., 1992; Obeling & Poulsen, 1999).

Musicians are exposed to potentially hearing damaging sound levels and therefore have an occupational risk of NIHL as well as tinnitus (Laitinen et al., 2003; O'Brien et al., 2008; Schmidt et al., 2011). Furthermore, an association between loud sound exposure and hearing loss in a dose-response dependent manner among musicians has been demonstrated (Royster et al., 1991; Schmidt et al., 2014b; Toppila et al., 2011). NIHL may, however, be associated with tinnitus, but a direct association between the level of the sound exposure and the development of tinnitus has not been demonstrated (Engdahl et al., 2012; Palmer et al., 2002). On the other hand, it has recently been shown in a few studies that tinnitus is significantly correlated to both leisure music exposure and occupational noise exposure in the general population (Guest et al., 2017; Moore et al., 2017). Most of the subjects in the study by Guest et al. (2017) had constant tinnitus but with a normal audiogram, whereas only a minority experienced constant tinnitus in the study by Moore et al. (2017) (Guest et al., 2017; Moore et al., 2017). Tinnitus may be a preliminary indicator of hearing loss, and there is some evidence that tinnitus may be noise induced even in the presence of normal hearing thresholds (Guest et al., 2017; Hickox & Liberman, 2014; Lindblad et al., 2014; Schaette & McAlpine, 2011).

It is evident from the study by Moore et al. (2017) that many subjects have temporary tinnitus and a possible explanation is occasional noise exposure from music at clubs or concert venues (Moore et al., 2017). The occasional noise exposure resulting in temporary threshold shifts may also be a good explanation of the high tinnitus prevalence reported among musicians. However, it is unknown if the severity of tinnitus is related to the accumulated lifetime noise exposure, ageing, or other factors.

This study aims to: (1) describe the epidemiology of tinnitus in classical orchestra musicians including characterizing the severity of tinnitus, (2) investigate the relationship between tinnitus severity and hearing impairment, (3) investigate the association between tinnitus severity in classical musicians and their cumulative lifetime sound exposure.

SUBJECTS AND METHODS

Population

The study was conducted among a population of classical orchestra musicians (aged 21–68 years) from five Danish symphony orchestras. Data were collected from 2007 to 2010. During this period, 443 musicians were employed in the symphony orchestras, and all were offered the opportunity to participate in the study questionnaire (Schmidt et al., 2014b). In total, 325 musicians (response rate, 73.4 %) answered the questions regarding tinnitus and are included in the analyses in the present study.

Questionnaire

The questions posed to the musicians in this study covered different aspects of their work and personal health. Questionnaire items screening for tinnitus and the impact hereof at work and outside work was developed in corporation with specialized doctors in audiology. The face validity of all questionnaire items including the questions in the present study was tested on musicians and music students as previously reported for a study of musculoskeletal problems in classical orchestra musicians (Paarup et al., 2011). The construct validity of the exposure time variables in this questionnaire was furthermore tested in a study specifically examining the relationship between sound exposures and hearing thresholds in musicians (Schmidt et al., 2014b). In addition, internal consistency between specific items was performed as reported in the present study.

To calculate the cumulative duration of the sound exposure during a musician's entire lifetime, the musicians were asked to list the number of weekly hours dedicated to musical activities such as individual practice, group rehearsal concerts, and other musical activities. Furthermore, the total number of years playing their main instrument and any previous main instruments was also recorded. Time periods during the year when the musicians did not engage in musical activities such as holidays were also recorded. To estimate the total exposure time, a yearly exposure time was calculated and multiplied by the number of years the musician has played his/her main instrument (Schmidt et al., 2014b). If the main instrument has been switched during the career, the exposure time was then calculated separately for the number of different instruments to produce a more accurate estimate of their accumulated exposure.

Any tinnitus was defined in the questionnaire as ringing, wheezing, or buzzing sound lasting more than 5 minutes in one or both ears without an obvious external source of this particular sound. The following questions were asked: "Do you have or have you had tinnitus?" (Yes/No). "How do you experience your tinnitus?" (Constantly/Intermittent). "In which ear do you have tinnitus?" (Right/Left/Both). To characterize tinnitus severity, two questions about the impact on their daily life as a musician inside or outside the orchestra were asked: "Is tinnitus a problem to you inside the orchestra?" (Yes - absolutely, Yes - to a certain extent, Yes - but only little, No – not at all). "Is tinnitus a problem to you at other places (outside the orchestra)?" (Yes - absolutely, Yes - to a certain extent, Yes – but only little, No – not at all).

Sound Exposure

The sound exposure of musicians was based on measurements of rehearsals and performances in two different symphony orchestras with microphones attached to both the left and the right ear (Schmidt et al., 2011). Based on these measurements, the exposure was calculated for each instrument group, separately for the left and the right ear. The average exposure of the musicians ranged from 83.2 dB(A) (right ear double bass and left ear cello) to 92.7 dB(A) (right and left ear of trumpet players and left ear of viola players) (Schmidt et al., 2011; Schmidt et al., 2014b).

The annual sound immission level was calculated individually for each musician to be corresponding to 2080 hours, which is equal to 8 hours of exposure per day for 260 days/year. To calculate the entire life time sound immission, the number of years played were then taken into account in a method similar to the previously described noise immission level (Burns & Robinson, 1973; Schmidt et al., 2014b).

Audiometric Measurements

All available musicians were invited to take an audiometric test. A subgroup of 223 of 394 available musicians (57%) decided to participate in the audiometry test (Schmidt et al., 2014b). All participating subjects had an anamnestic interview and were examined in ear, nose, throat including otoscopy, and removal of obstructing cerumen before audiometry. Eleven subjects were excluded from the analyses because of medical history of previous ear disorders and audiometric findings suspicious of hearing loss caused by pathologies other than music exposure. Subjects with other medical conditions such as hypertension were included. Thus, 212 musicians' hearing status was examined as previously reported (Schmidt et al., 2014b). Among the 325 subjects who answered the questions regarding tinnitus, 174 also completed the audiometry test. Thus, complete data with audiometry as well as questionnaire data regarding exposure and tinnitus status existed for 174 subjects (367 tested ears as one participant only completed the audiometry on the left side).

The audiometry was performed as user-operated audiometry with the Two-Alternative Forced Choice paradigm at the workplaces in a quiet room. The audiometry was conducted with a computer (Compaq nx6310; Hewlett-Packard, Palo Alto, CA) connected to a digital signal processor (Mobile Processor RM2; Tucker Davis Technologies, Alachua, FL) and an audiometric headphone (HDA200; Sennheiser, Wedemark, Hannover, Lower Saxony, Germany) connected to the mobile processor. The frequencies 0.25, 0.5, 1, 2, 3, 4, 6, and 8 kHz were all tested on both ears and the average of 3, 4, and 6 kHz was calculated and used as a noise sensitive measure of high-frequency (HF) hearing thresholds in this study.

The audiometry method has previously been validated for reliability and comparability with traditional manual audiometry performed by a technically skilled person (Schmidt et al., 2014a). The reproducibility of user-operated audiometry is equal to or lower compared with manual audiometry, and thresholds were slightly but systematically lower on average 1.9 dB (Schmidt et al., 2014a; Schmidt et al., 2014b). Normal hearing was considered as any threshold lower than 10 dB HL in this study.

Statistical Analysis

To characterize tinnitus severity from the questions about the daily impact of tinnitus on the musicians' lives, two scales were derived from the questions addressing tinnitus problems inside and outside the orchestra. Based on the two questions, severe tinnitus was defined as subjects reporting any kind of tinnitus problems inside or outside the orchestra.

The epidemiology of tinnitus including tinnitus prevalence of any tinnitus and severe tinnitus were examined with descriptive statistics and Chi-squared tests of difference in the prevalence of tinnitus between male and female musicians as well as between different instrument groups.

To test the hypothesis that any tinnitus or severe tinnitus are associated with hearing thresholds and lifetime sound exposure logistic regression (command *logit* in STATA) was used. In these analyses, clusters related to individuals were included in the models as hearing thresholds and tinnitus from the right and left ear from each subject are correlated. Any tinnitus or severe tinnitus was analyzed as an outcome variable with gender as a dichotomous independent variable and HF hearing thresholds, age, and lifetime sound exposure as continuous independent variables in these analyses. Twenty-three subjects took antihypertensive medications. The variable of hypertension was included in all analyses but eliminated from all models using $p > 0.1$ as elimination criteria. Age and gender were, however, kept in all models despite the elimination criteria of $p > 0.1$.

The two scales of tinnitus severity inside or outside the orchestra were investigated for consistency between the two scales and their ability to demonstrate redundant items (questions) using Cronbach's alpha (Bland & Altman, 1997). These two scales were combined to characterize tinnitus severity by adding the response value of 0 to 3 depending on the response category in each question. Thus, the answer "No – not at all" had the value 0, "Yes – but only little" had the value 1, "Yes - to a certain extent" had the value 2, and "Yes – absolutely" had the value 3 in both of the questions. The sum of the response values from the two questions was then calculated to form the scale of tinnitus severity going from 0 when there was no impact of tinnitus inside or outside the orchestra to 6 when the musicians had severe problems and answered "Yes – absolutely" to both questions. On the other hand, category 1 was the least severe tinnitus case, which were subjects who answered "Yes – but only little" to only one of the questions. Tinnitus severity was calculated for a specific ear if tinnitus was reported to be localized to one ear only. In case of bilateral tinnitus, tinnitus severity was assumed to be equal in both ears.

TABLE 1. Descriptive Statistics of Gender Differences Among Musicians With or Without Tinnitus

Variable	Men	Women	Total
Tinnitus (yes/no) (%)	74/120 (38)	41/90 (31)	325
Mean age years by tinnitus groups (yes/no)	46.3/46.9	40.1/40.9	325
No ears with tinnitus (yes/no) (%)	110/278 (28)	57/205 (22)	650
Tinnitus, right ear only, n (%)	8 (47)	9 (53)	17
Tinnitus, left ear only, n (%)	22 (69)	10 (31)	32
Tinnitus, both ears, n (%)	40 (68)	19 (32)	59
Intermittent tinnitus, n (%)	37 (69)	17 (31)	54
Constant tinnitus, n (%)	11 (65)	6 (35)	17
Unspecified tinnitus, n (%)	22 (59)	15 (41)	37

Ordinal logistic regressions (command *ologit* in STATA) were used to test the hypothesis that tinnitus severity as an outcome is independent of lifetime sound exposure, hearing thresholds, age, and gender. A principal component analysis (command *pca* in STATA) was performed to identify the most important principal components explaining any association between the principal components and tinnitus severity. Underlying principal components were dependent on lifetime sound exposure, instruments specific sound exposure, exposure time, and age.

Wald $\chi 2$ tests were used to test statistic to test for significance of the logistic and ordinal logistic regression models.

All analyses were performed using STATA SE version 14.0 (Stata Corp., College Station, TX).

RESULTS

Tinnitus Epidemiology

Data collected from the questionnaire (Table 1) demonstrated that 35% of all musicians or 31% of all female musicians and 38% of all male musicians ($\chi^2(2,325) = 1.60$, $p = 0.20$) from five Danish symphony orchestras reported having experienced any tinnitus lasting for more than 5 minutes. Of these, 59/115 (51%) reported any tinnitus in both ears. Of the 49/115 (43 %) musicians with any tinnitus in one ear only (Table 1), 32 reported any tinnitus in the left ear, and 17 reported any tinnitus in the right ear (Table 1). Seven musicians only responded to the main tinnitus question and did not report on localization. In total, any tinnitus affected 28% of male musicians' ears and 22% of female musicians' ears ($\chi^2(2,650) = 3.56$, $p = 0.06$)) (Table 1). However, half of the musicians 54/108 (50%) reported that their tinnitus was only intermittent, whereas 17/108 (16%) musicians had tinnitus constantly.

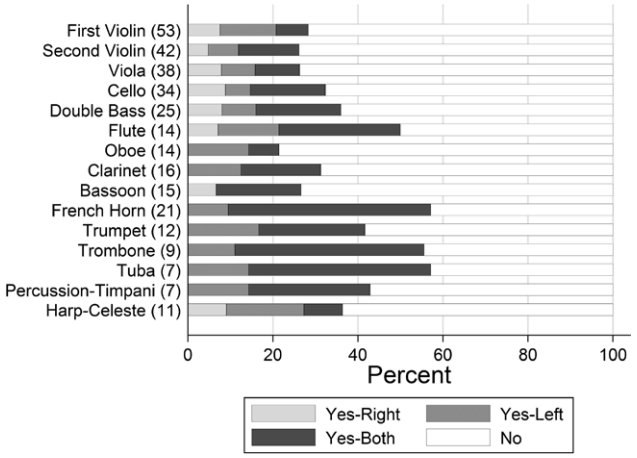

Figure 1. Percentage of musicians with single-sided or double-sided tinnitus shown by instrument type. Numbers in parenthesis are size of the instrument group.

Any tinnitus was reported in every instrument group (Fig. 1). Furthermore, the odds of having bilateral tinnitus was significant higher only for the brass players (trumpet, French horn, trombone, tuba) odds ratio (OR) = 3.68 (95% CI, 1.34–10.09) compared with other musicians and high-strings players (violin and viola) who had significantly higher odds of unilateral tinnitus OR = 2.62 (95% CI, 1.15–5.96) compared with other musicians. No significant differences in the odds of bilateral tinnitus were observed between low-string players (cello and double bass) OR = 1.02 (95% CI, 0.43–2.70), wood wind players (flute oboe, clarinet, bassoon) OR = 1.17 (95% CI, 0.43–3.20), percussion, timpani, harp, and celeste players OR = 0.60 (95% CI, 0.13–2.83) when compared with all other musicians.

Representativeness and Missing Data

The responders (n = 325) of the main tinnitus question defined the population of interest in this study. There were no significant differences in participation concerning sex ($\chi^2(1,443) = 1.93$, $p = 0.17$), orchestra of employee ($\chi^2(4,443) = 3.75$, $p = 0.44$) and instrument type ($\chi^2(16,443) = 20.68$, $p = 0.19$) between responders and nonresponders of the questionnaire, and no significant differences concerning sex ($\chi^2(1,394) = 2.25$, $p = 0.13$) and instrument type ($\chi^2(16,394) = 11,13$, $p = 0.80$) were observed between audiometric participants and nonparticipants in the hearing test. However, the participation rate of the audiometric test was higher in one of the orchestras ($\chi^2(4,394) = 14,08$, $p = 0.007$). The nonresponders of the questionnaire were on average 4.7 years younger than the responders (t = -3.90, $p = 0.001$), but there was no significant difference in age between participants and nonparticipants of the audiometric test (t = -0.005, $p = 0.99$).

Questionnaires that were incomplete regarding exposure data or concerning tinnitus severity were left out of the particular analysis.

Tinnitus Severity

Figure 2A and B demonstrate two scales of tinnitus severity whether the musicians considered tinnitus to be a problem when playing inside and outside the orchestra, respectively. Tinnitus severity was demonstrated to be worse among the wind players (woodwinds and brass players) compared with the string players (violin, viola, cello, double bass) with respect to the impact of

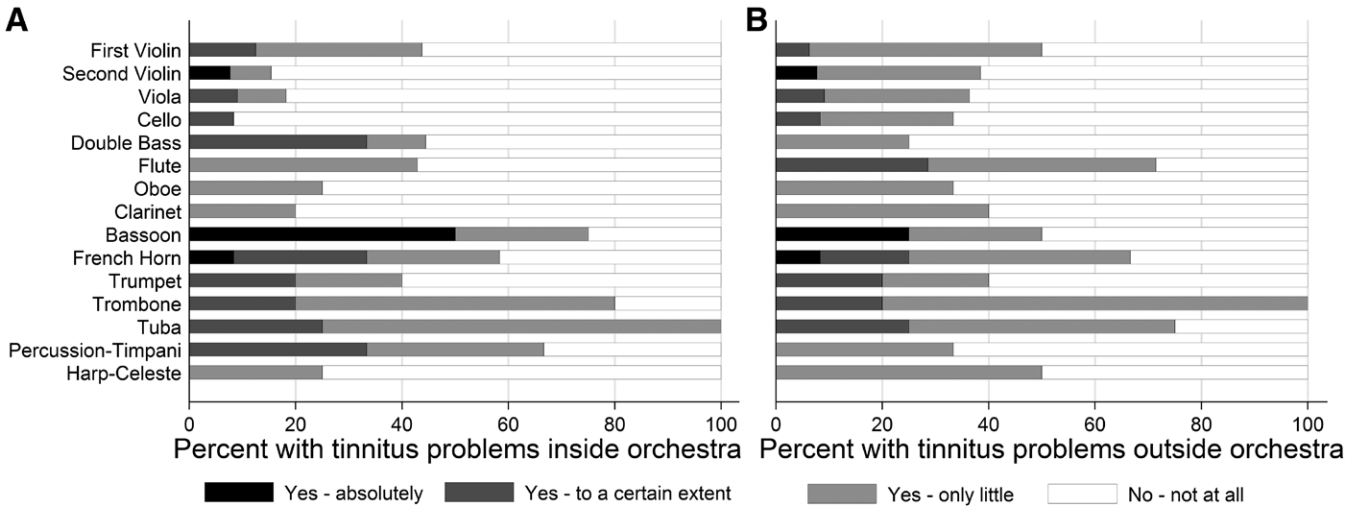

Figure 2. A, The percentage of answers to the question: "Is tinnitus a problem to you inside the orchestra" among different instrument types. B, The percentage of answers to the question: "Is tinnitus a problem to you at other places" viz. outside the orchestra among different instrument types.

tinnitus inside the orchestra ($\chi^2(3,115) = 11.66$, $p = 0.009$); oboe and clarinet players did not report these findings.

Woodwinds and brass players reported that their tinnitus was more severe outside the orchestra compared with the severity reported by string players do ($\chi^2(3,113) = 8.15$, n = 113, $p = 0.04$).

Comparing Figure 2A with Figure 2B, it can be seen that musicians in general regard tinnitus as a problem during activities performed outside the orchestra compared with when sitting in the orchestra. On the other hand, double bass players and percussion/timpani players regarded tinnitus to be a more severe problem in the orchestra compared with situations outside the orchestra. Tinnitus was more severe in the orchestra if tinnitus severity was reported in a higher category as an answer to the question about tinnitus problems inside the orchestra compared with the question addressing tinnitus problems outside the orchestra (Fig. 2A, B). Compared with all other musicians, only double bass players ($\chi^2(1,114) = 11.62$, n = 114, $p = 0.001$) and percussion/timpani players ($\chi^2(1,114) = 6.00$, n = 114, $p = 0.01$) reported significant differences in the severity of tinnitus between the two situations.

Intermittent tinnitus can be seen after periods with high sound exposure. It was demonstrated that intermittent tinnitus was generally rated as less severe inside ($\chi^2(3,75) = 13.22$, $p = 0.004$) as well as outside ($\chi^2(3,73) = 8.80$, $p = 0.03$) the orchestra compared with constant tinnitus.

Tinnitus and Hearing Thresholds

Any tinnitus lasting more for than 5 minutes was used as the definition of any tinnitus. Severe tinnitus was defined as tinnitus with an impact on daily life within the orchestra or outside the orchestra using the two scales of tinnitus severity.

Occurrence of severe tinnitus was dichotomized based on whether the reported tinnitus was considered being a problem (no matter the severity degree) or not at all. Thus, on each of the two scales, only musicians who perceived their tinnitus as a problem would have been counted as having severe tinnitus in the orchestra or outside the orchestra or in both situations. Furthermore, the two locations where tinnitus severity was assessed (inside and outside the orchestra, respectively) were combined to form a new scale to characterize the overall tinnitus severity of a single musician ear. Overall, 19% of the musicians (21% of the male musicians and 18% of the female musicians) reported severe tinnitus in one or both ears using this definition.

The ORs of having any tinnitus (OR = 1.03 [95% CI, 1.00–1.06]) or severe tinnitus (OR = 1.03 [95% CI, 1.00–1.06]) were significantly related to any 1 dB increase in HF hearing thresholds.

However, as shown in Table 2, lifetime sound exposure was a better predictor of both any tinnitus and severe tinnitus than HF hearing thresholds, age, and gender. The odds ratio of an event of any tinnitus is then OR = 1.13 (95% CI, 1.04–1.23) for every 1 dB increase in lifetime sound exposure and the odds ratio of an event of severe tinnitus with impact on daily life in the orchestra, outside the orchestra, or in both situations is 1.23 (95% CI, 1.12–1.36).

TABLE 2. Odds Ratios of Associations Between Any Tinnitus and Severe Tinnitus Outcomes and Lifetime Sound Exposure Adjusted for 3, 4, 6 kHz Hearing Thresholds, Age, and Gender

	Model 1	Model 2
	Any Tinnitus	Severe Tinnitus (Combined)
	N = 347	N = 345
Wald chi (4 d.f)	17.3	21.3
Hearing threshold	1.01 (0.98–1.04) $p = 0.57$	1.01 (0.97 – 1.05) $p = 0.51$
Age	1.01 (0.98–1.05) $p = 0.52$	1.00 (0.95–1.04) $p = 0.88$
Gender (ref. male)	0.57 (0.28–1.18) $p = 0.13$	0.60 (0.23–1.55) $p = 0.30$
Lifetime sound exposure	1.13 (1.04–1.23) $p = 0.006$	1.23 (1.12–1.36) $p < 0.001$

N = number of respondents to the questionnaire items in the statistic model. Numbers vary between the models due to missing answers in some questions.
Model 1: Outcome is "any tinnitus" (yes/no).
Model 2: Outcome is "severe tinnitus problems" (yes/no). This model reflects a scale based on a combination of the tinnitus questions containing only musicians who perceived their tinnitus as a problem inside or outside the orchestra.

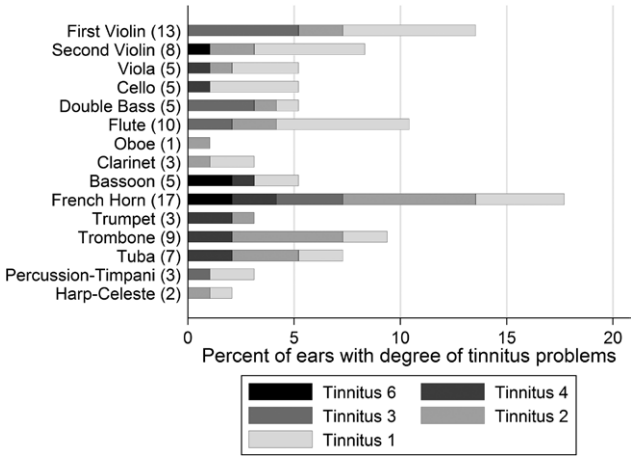

Figure 3. Different degrees of tinnitus severity based on the two questions concerning tinnitus severity (Fig. 2). The scale consists of six tinnitus categories from one to six, where the highest number or the darkest gray tone represents subjects where tinnitus is most severe. The number in parenthesis is the number of musicians with severe tinnitus symptoms in each instrument group. No musicians fell into the Tinnitus 5 group.

Tinnitus Severity and the Relation to Lifetime Sound Exposure

It is evident from Table 2 that severe tinnitus inside or outside the orchestra are related to lifetime sound exposure. It was therefore analyzed if the two items addressing tinnitus severity were redundant with one another, and to accomplish this, the internal consistency of the scales of the two items was tested using Cronbach's alpha. The scale reliability coefficient was 0.84, suggesting high internal consistency. As the Cronbach's alpha coefficient did not exceeded 0.9, which has been recommended as an upper limit of the Cronbach's alpha coefficient (Bland & Altman, 1997), the two subscales were considered not redundant with one another.

Tinnitus severity can therefore be graduated even further based on the impact of tinnitus on daily life inside and outside the orchestra in a combined scale. The distribution of the graduated problems of severe tinnitus between the different instrument groups according to the new combined scale of tinnitus severity is demonstrated in Figure 3. It is evident from Figure 3 that tinnitus is regarded as problem within all instrument groups, but especially the first violinists, French horn players and flute players account for a large majority of the musicians with severe tinnitus. The highest degree of tinnitus severity (category 4–6) is more frequent among the wind players, and it is also evident from Figure 2 that tinnitus severity is larger in wind players compared with the string players ($\chi^2(5,611) = 39.66$, $p < 0.001$). Musicians with severe tinnitus were then compared with musicians who did not regard tinnitus as a problem and with this dichotomization it was still evident that severe tinnitus was significantly more frequent in wind players compared with string players ($\chi^2(1,611) = 29.00$, $p < 0.001$).

Tinnitus is a symptom, which may be dependent on age, gender, hearing thresholds, and the sound exposure, but it is not known if the degree of tinnitus severity is dependent on these factors.

Ordinal logistic regression analyses were then used to test the hypothesis that the degree of tinnitus severity depends on sound exposure, age, gender, and hearing thresholds. As it can be seen in Table 3, model 1 demonstrates a significantly increased OR of 1.16 (95% CI, 1.07–1.24) in tinnitus severity for every unit of the scale presented in Figure 3 if the entire life time sound exposure is increased with 1 dB. This OR is increased to 1.25 (95% CI, 1.12–1.40) if the musicians' HF hearing thresholds are included in the model (model 2). Model 2 also shows that hearing thresholds do not significantly predict tinnitus severity in musicians. Thus, poorer hearing does not result in the perception of more severe tinnitus. Restricting the population to the musicians with normal hearing with hearing thresholds of any frequency better than 10 dBHL (model 3) results in an odds ratio of 1.27 (95% CI, 1.09–1.49), indicating that tinnitus severity seems to be dependent on the sound exposure among the normally hearing musicians as well.

The investigation of the association between lifetime sound exposure and tinnitus severity was performed with a principal component analysis. Table 4 shows the principal component analysis and demonstrates that component 1 (total lifetime exposure) was the most important variable with an eigen value of 2.05 and explains 51% of the variance in the model. Table 5 shows that lifetime sound exposure and the instrument-specific sound exposure are the most important factors explaining the underlying principal component 1, where time components such as exposure time and age are less important. Principal component 2 is more dependent on time (Table 5), where time variables such as age and exposure time are positive compared with the negative values associated with variables related to sound. Thus, it is evident that the sound exposure level plays a more important role compared with the exposure time when explaining the association between lifetime sound exposure and tinnitus severity.

Table 3, model 4, indicates that the underlying principal component one is the most important component. Measures of sound exposure are the main components of component 1, and an increase in sound exposure is a significant factor contributing to increased tinnitus severity in musicians with an odds ratio of 1.44 (95% CI, 1.18–1.76).

DISCUSSION

This study demonstrates that the occurrence of any tinnitus and severe tinnitus in professional classical musicians is associated with lifetime sound exposure. Additionally, increased tinnitus severity is also associated with lifetime sound exposure. Sound exposure directly affects the outcomes of any tinnitus and severe tinnitus as there was no correlation between measured hearing thresholds and the two outcomes of tinnitus as well as increasing tinnitus severity.

Two different tinnitus definitions were used in this study. One definition was based on any kind of tinnitus lasting for at least 5 minutes and showed that 35% of all musicians reported tinnitus. Additionally, a definition based on severe tinnitus problems, which have an impact on daily life activities inside and outside the orchestra, showed that 19% of all musicians reported severe tinnitus. In general, musicians report any tinnitus more often than the general population where it is generally accepted that 10 to 15% of the population suffers from tinnitus (Lockwood et al., 2002). It may be difficult to compare the prevalence estimates from this study with a population-specific prevalence directly due to large differences between the populations because the population differences are not

TABLE 3. Ordered Logistic Regression of Tinnitus Severity in Relation to Explanatory Factors

	Model 1	Model 2	Model 3	Model 4
	N = 625	N = 345	N = 93	N = 615
Wald χ^2	16.1	18.9	10.7	17.9
Pseudo R^2	0.03	0.07	0.06	0.03
Lifetime sound exposure	1.16 (1.07–1.24), $p < 0.001$	1.25 (1.12–1.40), $p < 0.001$	1.27 (1.09–1.49), $p = 0.002$	
Age	1.00 (0.98–1.03), $p = 0.86$	1.00 (0.95–1.04), $p = 0.85$	0.98 (0.89–1.07), $p = 0.60$	
Gender (ref. male)	0.90 (0.50–1.62), $p = 0.72$	0.57 (0.22–1.42), $p = 0.23$	0.70 (0.10–4.92), $p = 0.72$	
HF hearing threshold (3, 4, 6 kHz)		1.01 (0.98–1.06), $p = 0.47$	1.09 (0.88–1.35) $p = 0.43$	
Component 1 (lifetime sound exposure)				1.44 (1.18–1.76), $p < 0.001$
Component 2 (total exposure time)				0.71 (0.76–1.12), $p = 0.32$
Component 3 (age)				1.21 (0.87–1.69), $p = 0.26$
Component 4 (instrument specific)				0.35 (0.09–1.34), $p = 0.13$

All models control for age and sex.
Model 1: All respondents' ears to estimate tinnitus severity and the lifetime sound exposure.
Model 2: A subpopulation of model 1 including only the ears, where the hearing thresholds were measured.
Model 3: A subpopulation of model 2 including only the ears where all measured frequencies indicate that no hearing loss is present. The hearing thresholds were included as continuous variable in the model but only for the normal-hearing subjects.
Model 4: Same population as model 1, but the four principal components of life time sound exposure tested as explanatory factors (Tables 4 and 5).

only related to the music exposure. Some evidence of a higher occurrence of any tinnitus among musicians compared with the background population exists, however, as it was shown that the incidence rate ratio of musicians with tinnitus was 1.45 compared with the background population. Furthermore, studies using the widest possible tinnitus definition of any tinnitus show that up to 25.3% of the entire population suffers from tinnitus (Shargorodsky et al., 2010). If this prevalence is compared with the prevalence in the present study, it still points toward an even higher prevalence of any tinnitus among musicians.

Laitinen and Poulsen (2008) defined tinnitus as the phantom sensation of sounds lasting for more than 5 minutes and by using this definition they showed that 21% of the musicians reported tinnitus, which was lower but somewhat comparable with the results presented in this study (Laitinen & Poulsen, 2008). Overall, different studies report a relatively high frequency of tinnitus symptoms between 21 and 51% of the musicians studied (Emmerich et al., 2008; Jansen et al., 2009; Laitinen & Poulsen, 2008; O'Brien et al., 2008). Thus, the reported prevalence of 35% of any tinnitus and 19% of severe tinnitus in the present study is comparable with previous studies.

TABLE 4. Principal Component Analysis of Total Life Time Exposure

Component	Eigen Value	Proportion	Cumulative
Component 1 (sound exposure)	2.05	0.51	0.51
Component 2 (exposure time)	1.35	0.34	0.85
Component 3 (age)	0.55	0.14	0.99
Component 4 (instrument specific)	0.06	0.01	1.00

Variables included are the lifetime sound exposure, the instrument-specific sound exposure, the total exposure time, the age. N = 646 ears. The eigen value of each component is presented and the proportion of the explained variance of each component in the model. The cumulative proportions of the components are shown in the last column. The explanation of the most important factors of each component is described in the parenthesis and based on the correlation matrix shown in Table 5.

Musicians frequently report tinnitus, but not all of them consider their tinnitus as a problem interfering with daily activities. That tinnitus is not regarded a problem this could be due to the fact that the tinnitus is intermittent and occasionally experienced after periods with loud sound exposure. On the other hand, tinnitus, which is constant and that causes an impact on daily activities inside and outside the orchestra, may be debilitating especially if it threatens the musician's career. Tinnitus may signal a subjective hearing problem even if it as was shown in this study, the tinnitus was not related to HF hearing thresholds. Musicians are particularly sensitive to symptoms related to hearing, as this sense is vital for their function as a professional musician. Future longitudinal studies are needed to determine if tinnitus symptoms are one of the main reasons explaining why musicians quit working in a symphony orchestra before retirement.

While tinnitus is a frequent symptom reported by classical orchestra musicians, there have not been any studies so far examining the association between the accumulated sound exposure and the tinnitus symptom (Emmerich et al., 2008; Jansen et al., 2009; Laitinen & Poulsen, 2008; O'Brien et al., 2008). These studies only report a quite high frequency of tinnitus symptoms between 21 and 51% of the musicians (Emmerich et al., 2008; Jansen et al., 2009; Laitinen & Poulsen, 2008; O'Brien et al., 2008).

Our study also demonstrated that the tinnitus symptom may differ among the different instrument groups. This is well correlated with the sound exposure. Brass instrumentalists report significantly more frequent tinnitus compared with string instrumentalists, and they have the most extensive sound exposure (Laitinen et al., 2003; O'Brien et al., 2008; Schmidt et al., 2011; Wilson et al., 2013). Furthermore, it is evident that left ear tinnitus is more frequent than both right ear tinnitus and bilateral tinnitus, and especially among high string players who hold their instruments closer to their left ear.

TABLE 5. Principal Component Analyses

Variable	Component 1	Component 2	Component 3	Component 4
Life time sound exposure	0.67	-0.18	-0.01	-0.72
Instrument sound exposure	0.52	-0.55	0.19	0.63
Total exposure time	0.44	0.50	-0.69	0.29
Age	0.29	0.64	0.70	0.11

This is a correlation matrix (eigen vectors) of how the different variables correlate with the underlying principal components.

Although left-sided tinnitus is for unknown reasons also more common in the population compared with right-sided tinnitus (Baguley et al., 2013), high string musicians have a significant asymmetric exposure and a predominant left-sided hearing loss (Royster et al., 1991; Schmidt et al., 2011; Schmidt et al., 2014b).

Sound exposure independently affects tinnitus and hearing thresholds. The association between the accumulated sound exposure and elevated HF hearing thresholds in musicians is well known (Royster et al., 1991; Schmidt et al., 2014b; Toppila et al., 2011), but our study showed that both the occurrence and severity of tinnitus are significantly associated with the accumulated lifetime sound exposure. Therefore, it is expected that the HF hearing thresholds would be significantly increased in musicians with tinnitus. However, this was not demonstrated in this study when the lifetime sound exposure was taken into account (Table 2). This indicates that the lifetime sound exposure is strongly associated with tinnitus than HF hearing thresholds are. Principal component analysis shows that the most important component (component 1) explains 51% of the variance (Table 4). Furthermore, component 1 consists mainly of components related to sound exposure, which are the lifetime sound exposure and the instrument type. Time components such as total exposure time and age are less important (Table 5). Thus, sound is the most important component explaining the association between the lifetime sound exposure and tinnitus (Table 5).

However, when analyzing the severity of the tinnitus symptom, it was demonstrated that only the lifetime sound exposure was significantly associated with a worsening of the tinnitus symptom (Table 3).

Interestingly, this study also demonstrates that increased accumulated lifetime sound exposure is associated with worsening of the tinnitus symptom even in completely normal-hearing musicians (Table 3).

It may be speculated that the tinnitus symptom may be an early warning of hearing loss or it may represent early changes in the auditory nerve (Lindblad et al., 2014; Schaette and McAlpine 2011). Additionally, tinnitus is associated with previous noise exposure including music, which supports the findings of the present study (Guest et al., 2017; Moore et al., 2017). Furthermore, it has also been demonstrated that the amplitudes of the auditory brain stem response decreased in normal noise exposed individuals compared with normal-hearing subjects without noise exposure (Stamper & Johnson, 2015). This could reflect early changes of the spiral ganglion neurons in the auditory nerve, and it may be speculated that tinnitus symptoms reflects an underlying early pathology in the auditory nerve as well. However, a similar study of normal-hearing subjects could not demonstrate an association between historic noise exposure and changes in amplitudes of the auditory brainstem response (Prendergast et al., 2017). It is therefore still largely unknown if noise exposure leads to changes in the function of the auditory nerve. Early pathology in the auditory nerve, if it exists, may, however, explain why deafferentation possibly can lead to reduced signal input to the auditory system and result in tinnitus (Eggermont & Roberts, 2004). Thus, future research is needed to establish evidence enough to coin noise exposure, tinnitus, and auditory neuropathy.

Limitations of the Study

Some limitations with the present study have to be considered. The study may be subject to selection bias. Our orchestra musicians have worked for several years and musicians with an increased tendency to severe tinnitus and hearing loss might have left the orchestras. Hence, the association between the accumulated lifetime sound exposure and the severity of tinnitus may be even more significant than measured. Furthermore, tinnitus severity was defined using a nonstandardized scale with two simple questions addressing if tinnitus is a problem for the musician inside and outside the orchestra. These questions may not accurately quantify tinnitus severity experienced by musicians in their daily life, and it is therefore difficult to compare the tinnitus severity measured in this study with studies using other measures of tinnitus severity such as the Tinnitus Handicap Index. Additionally, other medical conditions may interfere with the results if tinnitus is more frequent in relation to certain medical conditions among this hypertension. Therefore, an analysis was performed to investigate whether subjects with hypertension showed different results; however, this was not the case. Antihypertensive drugs are frequently prescribed to patients with various cardiovascular diseases including diabetes. However, an effect caused by these diseases on the analyzed outcomes cannot totally be ruled out as it may be possible that subjects with mild type-2 diabetes and cardiovascular disease without hypertension were included as subjects in the present study.

The exposure was estimated from questionnaire data supplemented with the average exposure measurements of different classical music repertoires (Schmidt et al., 2011). Due to the uniform conditions for the single instrument groups, these may be considered representative, but minor variation between musicians within the instrument groups could be obscured (Schmidt et al., 2011; Schmidt et al., 2014b). The estimated sound exposure may be too high or too low, but the measurement error may affect the group of less and more exposed musicians equally. Furthermore, there is a systematic bias in the reported exposure time as musicians report more hours used for practice and rehearsals than they actually do, but this bias affects all musicians in the population equally (Schmidt et al., 2014b). A potential misclassification of the exposure may therefore not affect the reported results, where tinnitus in exposed musicians is compared with tinnitus in highly exposed musicians.

This study may be prone to nondifferential misclassifications, but no serious bias, thereby probably attenuating any correlations.

CONCLUSION

A prevalence of 35% of symphony orchestra musicians report any tinnitus, but only 21% of the male and 18% of the female musicians have severe tinnitus and consider their tinnitus being a problem. This study showed that the severity of tinnitus is dependent on the accumulated lifetime sound exposure, but independent of the HF hearing thresholds. Accumulated life-time sound exposure is therefore an important risk-factor among other known risk-factors of tinnitus in symphony orchestra musicians. Tinnitus may partly be explained by damage of the auditory system due to sound exposure, and future studies will be needed to clarify the exact pathology behind these findings.

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