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Original Article

Hearing thresholds, tinnitus, and headphone listening habits in nine-year-old children

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ABSTRACT

Objective: Investigate hearing function and headphone listening habits in nine-year-old Swedish children. *Design*: A cross-sectional study was conducted and included otoscopy, tympanometry, pure-tone audiometry, and spontaneous otoacoustic emissions (SOAE). A questionnaire was used to evaluate headphone listening habits, tinnitus, and hyperacusis. *Study sample*: A total of 415 children aged nine years. *Results*: The prevalence of a hearing threshold ≥20 dB HL at one or several frequencies was 53%, and the hearing thresholds at 6 and 8 kHz were higher than those at the low and mid frequencies. SOAEs were observed in 35% of the children, and the prevalence of tinnitus was 5.3%. No significant relationship between SOAE and tinnitus was found. Pure-tone audiometry showed poorer hearing thresholds in children with tinnitus and in children who regularly listened with headphones. *Conclusion*: The present study of hearing, listening habits, and tinnitus in nine-year old children is, to our knowledge, the largest study so far. The main findings were that hearing thresholds in the right ear were poorer in children who used headphones than in children not using them, which could be interpreted as headphone listening may have negative consequences to children's hearing. Children with tinnitus showed poorer hearing thresholds compared to children without tinnitus.

Key Words: Children, hearing loss, hearing threshold, listening habits, portable music players, SOAE, tinnitus, tympanometry

Introduction

Listening to music with portable music players is a common leisure activity in adolescents (Kim et al, 2009). Research has shown that adolescents and young adults (17–23 years) listen for 1.5 hours per day on average (ranging from 10 minutes to 4 hours) (Kumar et al, 2009). Furthermore, 80% of 13- to 18-year-olds listen to music using headphones for 1–3 hours per day (Kim et al, 2009). Current portable music player technology provides very good sound quality, (Kumar et al, 2009) reported that the sound level used by adolescents aged 17–23 years was 73–79 dB A on average (ranging from 40 to 93 dB A, depending on the device). The used sound level was not affected by whether the sound environment when listening was silent or noisy. Hearing function is affected by both long- and short-duration noise (Kujawa & Liberman, 2006). Studies on listening to music with headphones have indicated poorer hearing thresholds for adolescents and young adults who use headphones compared to those who do not use headphones (Kim et al, 2009; Kumar et al, 2009; Peng et al, 2007). Only a few studies have addressed listening habits with headphones and hearing function in adolescents, and to our knowledge, no such studies of nine-year-old children have been published previously, (Peng et al, 2007) and (Kim et al, 2009) concluded that long-term use of headphones in adolescents can impair hearing function and that the prevalence of hearing loss increased with increased years of use of portable music players with headphones. No studies have investigated hearing function and listening habits in nine-year-old children; therefore, this area of study deserves exploration. Hearing thresholds in children and adolescents vary between previous studies (Blandy & Lutman, 2005; Haapaniemi, 1996; Marcoux et al, 2012). In a population of 131 ten-year-old children (Haapaniemi, 1996), reported that the best hearing thresholds ranged from 2.7 dB HL

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Abbreviations

SOAE	Spontaneous otoacoustic emissions
TTS	Temporary threshold shift

at 0.25 kHz to 2.6 dB HL at 8 kHz (Blandy & Lutman, 2005) showed similar hearing thresholds in seven-year-olds ($n = 80$), whereas (Marcoux et al, 2012) reported poorer hearing thresholds in a population of 217 children and adolescents aged 10–17 years (10 dB HL at 0.5 kHz to 8 dB HL at 8 kHz) (Shargorodsky et al, 2010) showed that the prevalence of hearing loss has increased since 1988 and that 19.5% of adolescents (12–19 years) had a pure-tone average (PTA, 0.5, 1, 2 kHz) worse than 15 dB HL. Even minimal, monaural, or binaural sensorineural hearing loss has been shown to have negative impacts on learning ability, language development, and performance in school (Jamieson et al, 2004; Daud et al, 2010).

Hearing disorders are not restricted to hearing loss; they also involve tinnitus and hyperacusis. Research has shown that the prevalence of tinnitus increases with age (Widén & Erlandsson, 2004) reported an increase in tinnitus in adolescents 13–19 years old. Previous research is inconsistent in terms of the prevalence of tinnitus in children (age 9–19), for whom reported prevalences vary between 6.8% (Widén & Erlandsson, 2004) and 14% (Holgers & Juul, 2006). Thus, knowledge regarding the prevalence of tinnitus in nine-year-old children remains limited.

Children are exposed daily to sound in traffic, pre-school, school, and leisure activities; therefore, it is important to investigate how this exposure affects the hearing of children and what we can do to protect against this exposure. It is also important to know the current status of hearing function in children because hearing loss at young ages can have consequences in school in terms of learning difficulties, and because hearing ability deteriorates later in life.

One conclusion from the above-mentioned research is that conflicting results have been found regarding the hearing function and listening habits of children and that there is a lack of information for this specific age group. The aims of the study were to investigate the hearing function and headphone listening habits and to analyse possible differences due to listening habits in nine-year-old Swedish children.

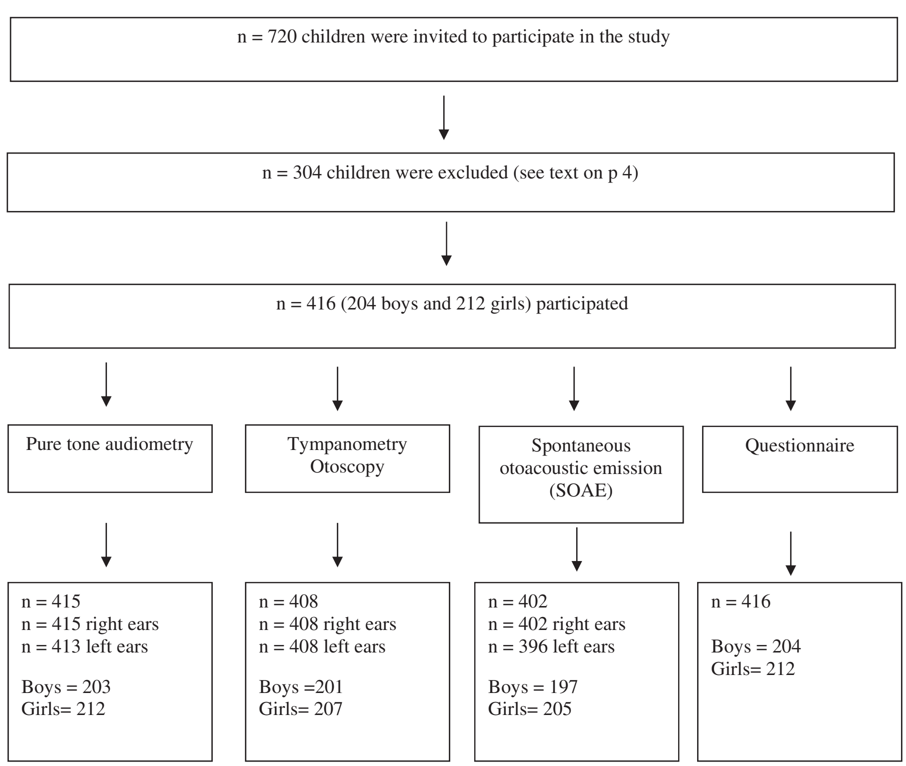
Materials and Methods

Participants

The study was performed in 21 schools located in rural and urban areas around the middle part of Sweden, and nine-year-old children were invited to participate. The invitations and informed consent were sent to the caregivers together with two letters with information regarding the study, one for the caregivers and one for the children. Within each school, 50% of the children were randomly selected. The exclusion criteria were as follows: absence of informed consent, poor Swedish language knowledge (assessed by the teacher), or the presence of a known cold, ventilation tubes, or tympanic membrane perforations. The number of included children and the methods are presented in Table 1.

Some children were excluded due to common colds etc. ($n = 304$). The vast majority of children performed all tests and the questionnaire (see Table 1). The study was approved by the regional ethics board (Dnr: 2009/140).

Table 1. Overview of children and methods.



Measurements

All tests employed were conducted according to ISO 8253-1:2010 (ISO, 2010). The test procedures included otoscopy (in the case of abnormalities, no further tests were conducted) and tympanometry using Interacoustics Titan and Grason-Stadler Inc. Entomed devices with a 0.226-kHz probe tone. The tympanometry was categorized as normal (A) or abnormal (B with a flat tympanogram, and C with ≥ -200 daPa) (Jerger, 1970). Pure-tone audiometry was conducted by authorized audiologists using an Entomed SA 201 in a secluded room with low levels of infra-sound (<35 dB SPL). To ensure that ambient noise did not affect the results, attenuating headphones (Sennheiser HDA200) were used. The hearing thresholds were measured at the frequencies 0.25, 0.5, 1, 2, 3, 4, 6 and 8 kHz and were measured in the 0–75 dB HL range. Our criteria for designating a hearing threshold as not normal (called abnormal hearing threshold) were as follows: ≥20 dB HL at one or several frequencies or according to the pure-tone average (0.5, 1, 2, and 4 kHz) or the high-frequency PTA (4, 6, and 8 kHz). Spontaneous otoacoustic emissions (SOAEs) were measured in order to investigate whether SOAEs was more or less prevalent in relation to tinnitus and normal hearing thresholds. SOAEs were measured in the 0.8–6 kHz frequency band using an ILOv6 device from Otodynamics Ltd. SOAEs were considered to be present when at least one peak above the noise level was measured. If abnormal middle-ear function or abnormal hearing thresholds were detected, both the school health care administration and the caregivers were informed.

A questionnaire containing 11 questions was administered. The questionnaire was designed and pretested in five children in the same age range (8–9 years) to ensure clarity and understandability in the current age group. The first question addressed the child's self-rated quality of hearing. Questions 2–5 addressed perceived tinnitus, questions 6–9 addressed possible hyperacusis (abnormal sensitivity to everyday sound at normal loudness), and questions 10–11 addressed headphone listening habits. Both portable music players and computer games were listed as possibilities for headphone listening. The question regarding tinnitus was worded as follows: *Imagine that you are in a quiet room. Is it totally silent in your ears?* If the child answered no, a follow-up question was asked: *Can you describe the sounds?* After a discussion with the child regarding the characteristics of the sound, the audiologist categorized the sound into one of three different categories: buzzing, pure-tone, or roar. The audiologist also asked how often the sound was experienced, and the occurrence was categorized as seldom, 1–3 times/week, daily, or always/constant. Based on the discussion with the child regarding the character of the sound and how often it was experienced, the audiologist determined whether the symptoms could be classified as tinnitus. The same procedure was used for the hyperacusis question.

The listening habits with headphones were measured on a four-degree ordinal scale (never, seldom, 1–3 times a week, or every day). For the analysis of hearing thresholds, the children were dichotomized based on their listening habits: those who listened on a regular basis (1–3 times a week or every day) and those who never listened using headphones.

Statistical analysis

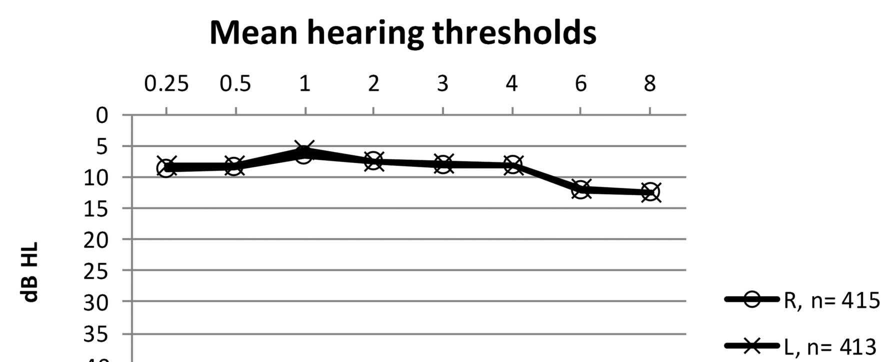
The data were analysed using IBM SPSS (21.0.0.0). Descriptive statistics were used to analyse the hearing thresholds and tympanometry results. A repeated measures ANOVA was used to compare hearing thresholds between groups (boys and girls, status of the middle ear, presence of tinnitus, presence of SOAEs, and headphone listening habits), as well as to analyse the differences in hearing thresholds between the right and left ears. A chi-squared test was used to evaluate differences regarding the prevalence of SOAEs (yes/no), hearing threshold ≥20 dB HL (yes/no), and status of the middle ear between independent groups (e.g. sex, and right and left ear). The prevalence of SOAEs was analysed in children with normal middle-ear function. Statistical significance was defined at $p < 0.05$.

Results

A significantly larger proportion of the girls displayed SOAEs. In contrast, the differences in tympanometry and in hearing thresholds were not dependent on gender.

Tympanometry

Of all of the children, 81.1% (331/408) had normal middle-ear function in both ears. No significant differences were found



	0.25	0.5	1	2	3	4	6	8
SD, R, n=415	6.3	6.1	5.8	5.8	6.2	6.4	7.2	7.5
SD, L, n=413	6.2	6.4	6.1	6.6	6.6	7.1	7.4	8.1

Figure 1. Mean hearing thresholds for the whole sample.

between the right and left ears. The prevalence of middle-ear abnormalities in both ears was 7.8% (32/408), and 11.0% (45/408) of the children had middle-ear abnormalities in one ear.

Pure-tone audiometry

HEARING THRESHOLDS

The mean hearing thresholds are presented for the right and left ears in Figure 1. No significant difference was found between the right and left ears. The figure shows a symmetrical hearing threshold >10 dB HL at 6 and 8 kHz in both ears. The standard deviations were slightly larger for the left ear.

The number of children with a hearing threshold ≥20 dB HL at one or more frequencies was determined (see Table 2); 53.2% (221/415) had a hearing threshold ≥20 dB HL at one or more frequencies in one or both ears. Table 2 shows the incidence of hearing loss among 221/415 children. In addition it is demonstrated that the vast majority, 154/415, had normal middle-ear function, while only 27/415 showed abnormal middle-ear function. Thus the abnormal middle-ear function does not explain the large number with hearing loss. Among children with normal middle-ear function, 37% showed a hearing threshold ≥20 dB HL at one or more frequencies; thus, their hearing thresholds at those

Table 2. Percentage and number of children with a hearing threshold ≥20 dB HL, in total, with normal middle-ear function and with abnormal middle-ear function.

Hearing threshold ≥20 dB HL at one or more frequencies	*% N*
Total number	53.2 (221/415)
Unilateral	31.0 (129/415)
Bilateral	22.1 (92/415)
With normal middle-ear function	
Total number	37.1 (154/415)
Unilateral	24.0 (100/415)
Bilateral	13.0 (54/415)
With abnormal middle-ear function	
Total number	6.5 (27/415)
Unilateral	2.4 (10/415)
Bilateral	4.1 (17/415)

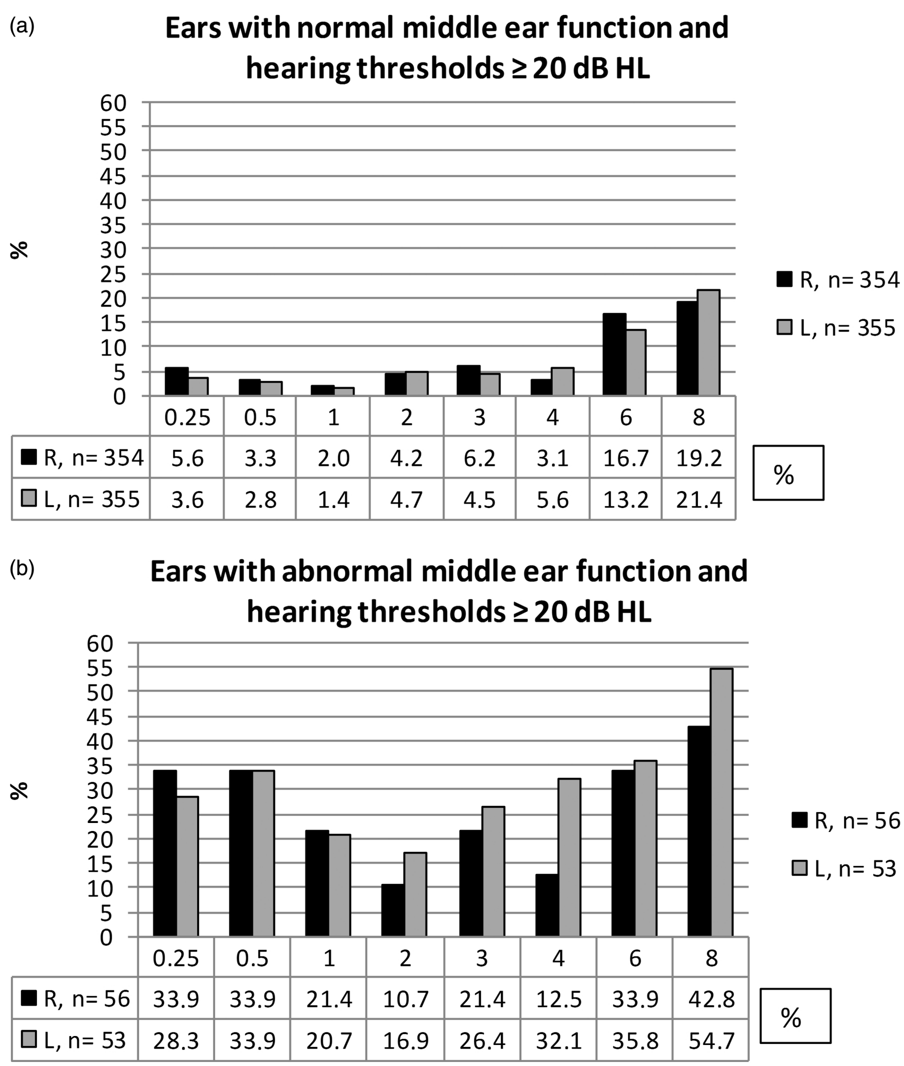
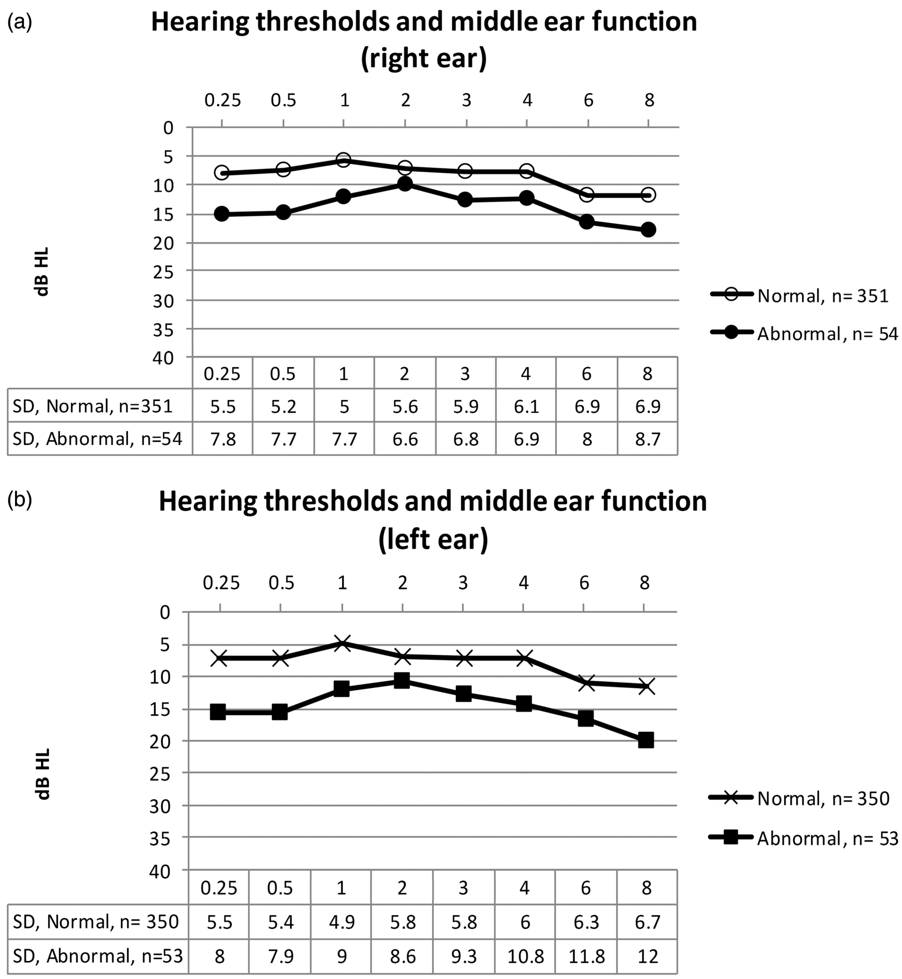


Figure 2. (a and b). Prevalence of a hearing threshold ≥20 dB HL at each frequency for ears with normal middle-ear function and ears with abnormal middle-ear function.



	0.25	0.5	1	2	3	4	6	8
SD, Normal, n=351	5.5	5.2	5	5.6	5.9	6.1	6.9	6.9
SD, Abnormal, n=54	7.8	7.7	7.7	6.6	6.8	6.9	8	8.7

	0.25	0.5	1	2	3	4	6	8
SD, Normal, n= 350	5.5	5.4	4.9	5.8	5.8	6	6.3	6.7
SD, Abnormal, n=53	8	7.9	9	8.6	9.3	10.8	11.8	12

Figure 3. (a and b). Mean hearing thresholds for ears with normal and abnormal middle-ear function.

frequencies likely indicated some sensory hearing loss (see Table 2).

The number of ears with pure-tone audiometry thresholds $\geq$20 dB HL at each frequency is shown in Figure 2 (a and b). Analysis of the number of children with normal middle-ear function and an abnormal hearing threshold, as indicated by a pure-tone average (0.5, 1, 2, and 4 kHz) $\geq$ 20 dB HL, revealed that 0.9% of the children had a bilateral abnormal hearing threshold and that 3.3% had a unilateral abnormal hearing threshold. The number of high-frequency PTAs (4, 6, and 8 kHz) $\geq$ 20 dB HL was also analysed; 0.6% had a binaural abnormal hearing threshold, and 3.3% had a monaural abnormal hearing threshold.

Hearing thresholds in relation to middle-ear status

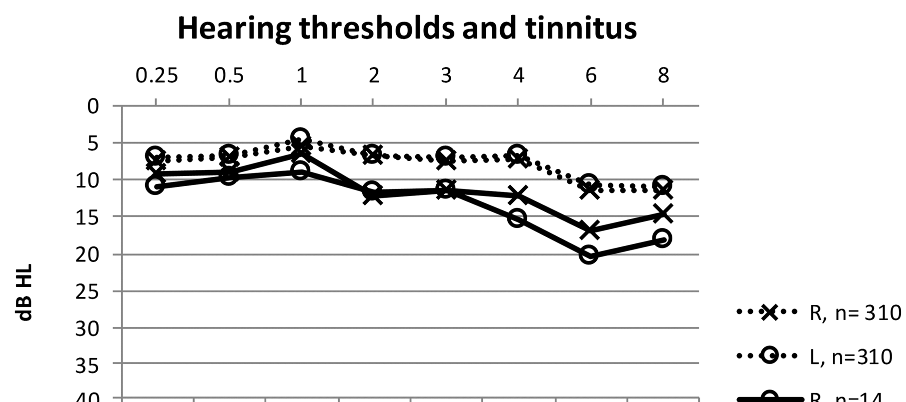
The mean hearing thresholds for ears with normal middle-ear function and ears with middle-ear abnormalities are presented in Figure 3(a and b). The ears with middle-ear abnormalities had significantly poorer mean hearing thresholds in both the right ($F = 75.396$; df =1; $p < 0.01$; $\eta^2 = 0.158$) and left ears ($F = 88.353$; df =1; $p < 0.01$; $\eta^2 = 0.181$). No differences were found between the left and right ears. The hearing thresholds were increased at the higher frequencies for both groups (normal middle-ear and abnormal middle-ear function).

Spontaneous otoacoustic emissions

Among children with normal middle-ear function, 35.2% (112/318) displayed SOAEs in one or both ears (monaural SOAEs, 19.2%; bilateral SOAEs, 16.0%). SOAEs were significantly more common in the right ear ($x^2 = 84.04$; df =1; $p < 0.05$, $N = 312$). In addition, children with SOAEs showed significantly poorer hearing thresholds in the right ear than children without SOAEs ($F = 6.534$; df =1; $p < 0.05$; $\eta^2 = 0.020$). A significantly larger proportion of girls (22.6%) displayed SOAEs compared to boys (12.5%) ($x^2 = 16.82$; df =2; $p < 0.05$, $N = 318$).

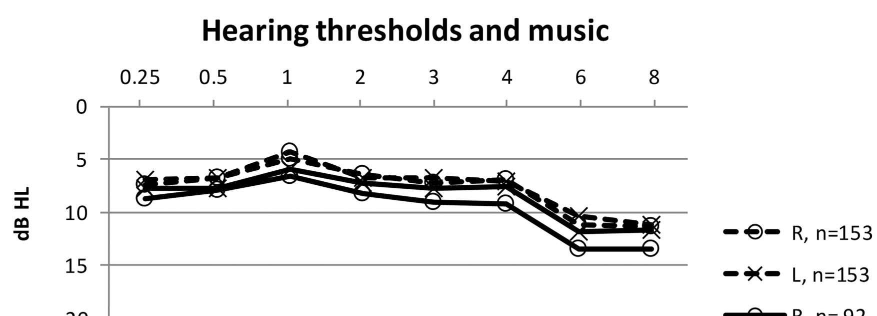
Tinnitus

Of the total population, 5.3% (21/411) reported tinnitus, and 14/21 perceived tinnitus on a daily basis (permanent). Of the 21 children, 14/21 showed normal middle-ear function, and 7/21 showed abnormal middle-ear function. The mean hearing thresholds for children with normal middle ears and tinnitus are compared with those for children with normal middle ears and without tinnitus in Figure 4. The children with tinnitus had significantly poorer hearing thresholds in both the right ($F = 22.224$; df =1; $p < 0.001$ $\eta^2 = 0.065$) and left ($F = 11.990$; df =1; $p < 0.001$; $\eta^2 = 0.036$) ears compared with those in the children without tinnitus. Among



	0.25	0.5	1	2	3	4	6	8
SD, R, 310	5.1	4.9	4.6	5.0	5.6	4.9	6.0	6.4
SD, L, 310	5.2	5.0	4.7	5.1	5.4	5.2	5.7	6.4
SD, R, 14	10.6	9.3	10.6	12.7	12.0	17.7	17.6	13.8
SD, L, 14	11.9	10.8	8.2	14.1	11.0	13.0	12.5	11.5

Figure 4. Hearing thresholds for children with normal middle-ear function. The dotted lines show the hearing thresholds for children without tinnitus, and the straight lines show the thresholds for children with tinnitus.



	0.25	0.5	1	2	3	4	6	8
SD, R, n=153	5.1	5.0	4.1	5.1	5.5	4.6	5.8	6.3
SD, L, n=153	5.1	4.8	4.4	5.3	5.6	5.2	5.6	6.6
SD, R, n= 92	6.1	5.4	5.7	6.6	6.7	8.3	9.0	8.4
SD, L, n= 92	6.3	6.2	5.6	7.5	6.4	6.9	7.1	7.1

Figure 5. Hearing thresholds for children with normal middle-ear function. The dotted lines show the hearing thresholds for children who do not listen with headphones, and the straight lines show the thresholds for children who do listen with headphones.

children with SOAEs in one or both ears, 4.5% (5/112) of the children perceived tinnitus. Only one child reported hyperacusis.

Listening habits with headphones

In total, 115/413 (27.8%) children listened daily or 1–3 times per week, compared with 102/413 (24.7%) who seldom listened and 196/413 (47.5%) who never listened with headphones. Among the 115 children who regularly listened to music (7/115), 6.0% reported tinnitus, which is comparable to the overall reported tinnitus rate of 5.3%. Analysis of the hearing thresholds for the children with normal middle-ear function showed that the children who listen to music 1–3 times/week or every day showed significantly poorer hearing thresholds in the right ear compared children who never listened ($F = 10.493$; df $=1$; $p < 0.001$; $\eta^2 = 0.041$) (see Figure 5).

Discussion

Pure-tone audiometry in children with normal middle-ear function showed increased hearing thresholds in 37% of the cases ($N = 154/415$). Only 6.5% of those with abnormal middle-ear function had a hearing threshold $\geq$20 dB HL at one or more frequencies. Therefore, increased hearing thresholds can not merely be explained by middle-ear dysfunction. About 50% had hearing thresholds $\geq$20 dB HL at one or more frequencies. Pure-tone audiometry showed that the children who listened to music 1–3 times/week or every day had significantly poorer hearing thresholds in the right ear. We found that 7.8% had bilateral middle-ear abnormalities with significantly poorer hearing. SOAEs were present in 35.2% of the children and was more common in girls and in the right ear. The overall prevalence of tinnitus was 5.3%.

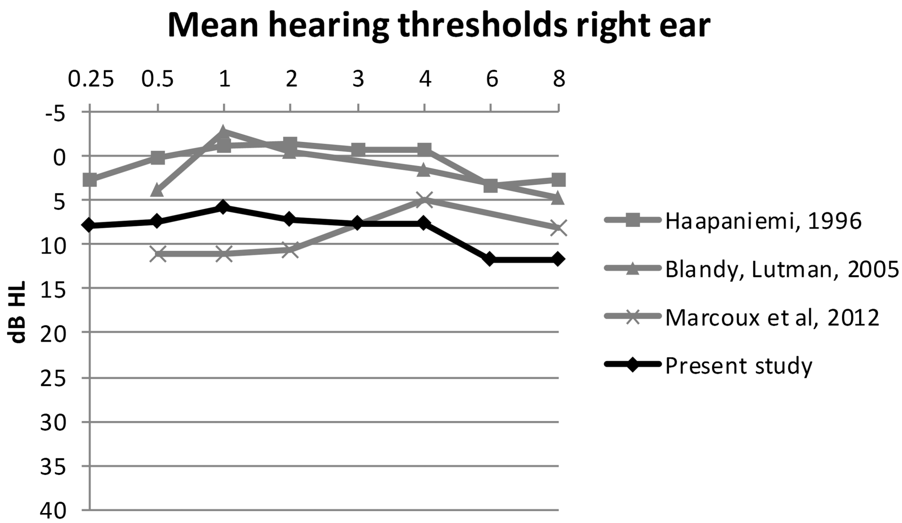


Figure 6. Comparison of hearing thresholds between different studies.

This was a field study, and the testing, which occurred in the schools, was not performed in a regular audio booth setting. However, the tests were conducted in a quiet test room (<35 dB SPL) by an experienced audiologist and with the use of attenuating headphones. As in all studies, ruling out a temporary threshold shift (TTS) is extremely difficult. Controlling all situations in all subjects before a hearing test is performed is virtually impossible. To the best of our knowledge, all children performed their hearing tests in conjunction with an ordinary classroom lecture, where no headphones have been used. Therefore, it seems unlikely that the hearing thresholds obtained could have been caused due to TTS. Using audiologists to test children is advantageous because the tests are valid and comparable to tests that are performed in audio booths. The testing included assessments of middle-ear function via tympanometry in addition to assessing hearing function, tympanometry also provides an estimation of the frequency of middle-ear dysfunction, which in most cases is caused by a serous otitis media. Abnormal middle-ear function results in a temporary abnormal hearing threshold, which can last months to years (Rovers et al, 2004). Our criterion for an abnormal hearing threshold was a hearing threshold ≥20 dB HL at one or several frequencies. Additionally, we used the pure-tone average (PTA4, 0.5, 1, 2, 4 kHz) and high-frequency PTA (4, 6, 8 kHz). Several other studies have used this criterion (≥20 dB HL) to evaluate hearing thresholds (Marcouq et al, 2012; Shargorodsky et al, 2010). This is a conservative limit for hearing loss (presented by (Northern & Downs, 2002) because even mild temporary and permanent hearing loss can have negative consequences on the perception and development of speech and language (Niskar et al, 1998).

We found bilateral and unilateral middle-ear abnormalities in 7.8% and 11.0% of the children, respectively. Our study found a higher prevalence of middle-ear abnormalities than that reported by (Holmes & Kaplan, 1997), who found a prevalence of 1.2% binaurally and 3.5% monaurally in 10- to 20-year old children and adolescents. In seven-year-old children (Blandy & Lutman, 2005) found a middle-ear abnormality prevalence of 11.3% with type B tympanometry and a prevalence of 23.8% for negative pressure using a threshold of ≤−150 daPa (Haapaniemi, 1997) showed that 14.5% of six- to nine-year-olds had abnormal middle-ear function, which is not in accordance with our study. These studies used different types of tympanometry equipment, and only one study reported the time of year at which the study was performed (Blundy & Lutman, 2005) September–December). Our data collection was performed from January–May and October–November. Because these studies were performed during school seasons, the data could have been skewed to some extent. Abnormal tympanometry in 18% of children with a significant abnormal hearing threshold will result in increased hearing difficulties in noisy classrooms with a risk of delayed language acquisition and poor academic results (Golz et al, 2005; Golz et al, 2006; Schilder et al, 1994). Children with repeated otitis media may also be at risk of a high-frequency abnormal hearing threshold (Hunter et al, 1996).

Pure-tone audiometry showed symmetrical hearing thresholds with an abnormal hearing threshold at 6 and 8 kHz, which was unexpected. Previous studies have reported different mean hearing thresholds (see Figure 6). The test conditions have also been varied, i.e. different audio booths and headphones. We used state-of-the-art clinical audiometers and tested in a silent room without any disturbing noise. The background noise was also evaluated to ensure a lack of interference with the audiometry.

The present study found generally poorer hearing thresholds and surprisingly poor hearing thresholds at 6 and 8 kHz compared with those in other studies. One possible reason for these results could be decreased hearing sensitivity as a result of early and continuous high sound exposure, as further demonstrated by the observation that the most recently tested age cohorts have poorer hearing thresholds (Shargorodsky et al, 2010) reported that the prevalence of hearing loss among 12- to 19-year-olds increased by 31% between the two NHANES studies, one between 1988 and 1994 and the other between 2005 and 2006 (from 14.9% to 19.5%). In the present study, 50% of the children had an abnormal hearing threshold (≥ 20 dB HL) at one or several frequencies. In contrast, in a Swedish study from 1987, 14% of ten-year-old children had a threshold >20 dB HL at one or several frequencies (Axelsson et al, 1987). Although the two studies had different criteria (≥20 dB HL and >20 dB HL), there appears to be a noticeable increase in the prevalence of hearing loss. Interestingly, the most affected hearing thresholds were at the same frequencies (6–8 kHz) among nine-year-old children, 6–20-year-old children, and adolescents (see Figure 6), which may indicate that hearing sensitivity has decreased in recent decades.

In the present study, we did not find any significant differences between the hearing thresholds of boys and girls or between the left and right ears; these results differed from those of previous studies (Blandy & Lutman, 2005; Holmes et al, 2004). This finding contrasts with that of (Haapaniemi, 1996), who found better hearing thresholds in girls than in boys. This discrepancy may have occurred because boys had noisier leisure activities 20 years ago, whereas today the games played by girls and boys are similar in terms of noise level. However, the present study reveals poorer hearing thresholds at 6 and 8 kHz, which is consistent with previous findings (see Figure 6).

The mean hearing thresholds for ears with abnormal middle-ear function were found to be significantly poorer compared with the thresholds in ears with normal middle-ear function. Because this abnormal middle-ear function can result in a temporary abnormal hearing threshold for several months, it is important to diagnose these children. This abnormal hearing threshold also occurs in frequencies in the range of speech; thus, it can affect the child's ability to hear speech and thus affect the child's learning abilities. Therefore, it is important for caregivers and teachers to be observant of symptoms of abnormal middle-ear function or abnormal hearing threshold. Some of these children may actually have a 'hidden' sensorineural abnormal hearing threshold that is thought to be caused by middle-ear effusion.

The prevalence of SOAEs was tested in our nine-year-old children to assess whether SOAEs were more or less prevalent in relation to the prevalence of tinnitus and normal hearing thresholds. In the present study, 35% of the children displayed SOAEs in one or both ears. We also found that SOAEs were more common in girls than in boys and that it was more common in the right ear. These results are in agreement with previous studies (Bilger et al, 1990; Groh et al, 2006). The hearing thresholds for children with SOAEs were poorer in the right ear, a finding that contrasts with previous research showing equal or better thresholds (Groh et al, 2006). Although the differences were significant, they were small (for example, children with no SOAEs had a threshold of 7 dB HL at 3 kHz compared with the 9 dB HL threshold for children with SOAEs). A difference in the prevalence of SOAEs between boys and girls and between the right and left ears was unlikely because the hearing thresholds were the same for both sexes and both ears. However, in 17- to 25-year-old males and females (Snihur & Hampson, 2011) reported a higher prevalence of SOAEs and better hearing thresholds for females than for males. An explanation for why SOAEs are more common in females has been proposed by (Bilger et al, 1990), who postulated that a genetic, X-linked component may cause the observed sex difference. Our findings for SOAEs and hearing thresholds show that presence of SOAEs does not appear to have noticeable predictive value for hearing thresholds. The low percentage of children with tinnitus and SOAEs (4.5%) does not support spontaneous emissions as a cause of tinnitus.

There is no consensus regarding the prevalence of tinnitus in children and adolescents. Previous studies in Sweden suggest that up to 14% of children and adolescents aged 9–16 years suffer from tinnitus (Holger & Juul, 2006). This high prevalence contrasts with previous studies and this study, which found a prevalence of 5.3%. The discrepancy among studies could be related to how the questions were asked (Holger & Juul, 2006) gave the children a lecture about hearing and tinnitus before the children filled in the questionnaire, which could have affected the children's answers and may explain the higher observed prevalence of tinnitus (14%), (Savastano, 2007) found that the prevalence of tinnitus was significantly higher when children were asked about tinnitus than when they spontaneously reported tinnitus, (Widén & Erlandsson, 2004) found a prevalence of 6.8% for permanent tinnitus in adolescents aged 13–15 years, which agrees with our finding, and both studies used a written questionnaire. In the present study, great care was taken in evaluating the prevalence of tinnitus. This study evaluated very young children; thus we wanted to have a discussion with the child before we determined that their perceived noise was really tinnitus. The assessment of tinnitus in young children in other, earlier studies has been criticized for using a method that was too difficult (questionnaires). The goal of this study was not to assess specific problems or issues regarding the perception of tinnitus, and we also had to limit our aims to perform this study. We believe that this procedure provided an approximate but valid estimated prevalence of 5%. This estimate appears to be valid and agrees with the authors' clinical experience in pediatric audiology. Although the observed prevalence of 5% in nine-year-old children is not alarming, several studies have shown that the prevalence of tinnitus increases with age (Widén & Erlandsson, 2004; Johansson & Arlinger, 2003) and that the prevalence in adults increases from 8% in the 20- to 50-year-old age group to 26.6% in the 70- to 80-year-old age group (Johansson & Arlinger, 2003).

We also found that a larger proportion of children with abnormal middle-ear function had tinnitus compared with that for children with normal middle-ear function (8.8% and 4.2%, respectively). This difference is important to consider when treating children with middle-ear abnormalities. Adverse outcomes have been suggested by (Savastano, 2007), who found that of the children with tinnitus, 59% had normal tympanometry, and 14.7% had abnormal middle-ear function (Savastano, 2007). The result provides important knowledge about the hearing performance and perception of tinnitus of nine-year-old children in the current Swedish population. Furthermore, this finding may serve as an important initiation point for other studies.

The hearing thresholds for children with tinnitus were significantly poorer than those for children without tinnitus in both ears (Figure 4). This result contrasts with that of (Juul et al, 2012), who found that the hearing thresholds did not differ between persons with and without tinnitus. However, in contrast to our study, Juul et al performed a screening audiometry at 20 dB HL (Marcoux et al, 2012; Juul et al, 2012) found that adolescents with tinnitus had significantly poorer hearing thresholds at 4 kHz in both the right and left ears.

In an older population (13- to 16-year-olds), 80% listened with headphones on a regular basis (Muchnik et al, 2012). In the present study, 27.5% of the nine-year-old children listened with headphones daily or 1–3 times per week. In the present study, pure-tone audiometry showed that children who listened to music 1–3 times/week or every day had significantly poorer hearing thresholds in the right ear. One can presume that the headphone listening habits will increase with age. This testing covers the typical frequencies of noise exposure, which is usually reported to be 4 and 6 kHz. We think that our results show a typical pattern of increased hearing thresholds at 4 and 6 kHz because we found poorer thresholds for the entire ear. Our findings indicating that hearing thresholds can be worsened in children who listen to music with headphones are similar to the findings in other studies (Kim et al, 2009; Peng et al, 2007; Feder et al, 2013). In the present study, we found that the hearing thresholds in the right ear were more affected than those of the left ear, whereas the previous studies did not report separate thresholds for the right and left ears (Peng et al, 2007). Additionally, all of the previous studies were performed in older subjects (Kim et al, 2009; Peng et al, 2007; Feder et al, 2013).

Although our differences were statistically significant, they were small, and the clinical relevance should be discussed. Previous research has shown that the ears of younger individuals that are affected by noise notches show accelerated hearing loss progression compared with that in the ears of individuals without noise notches (Kujawa & Liberman, 2006; Gates et al, 2000). Research has shown that listening to music on a regular basis can have a negative effect on outer hair cells, as measured by OAE, although the audiometric thresholds at the pure-tone average (0.5, 1, and 2 kHz) were normal (Kumar et al, 2009).

Several studies have demonstrated that children in pre-school and school are exposed daily to 58–69 dB A noise (Lunquist, 2003; Lundquist et al, 2000). It has been demonstrated that children who are exposed to noise >65 dB A show a decrease in understanding speech, and studies have reported that children with minimal sensorineural hearing loss had reduced academic performance (Jamieson et al, 2004; Daud et al, 2010).

Conclusions

In this very large representative sample of nine-year-old children, pure-tone audiometry showed that children who listened to music with headphones had significantly poorer hearing thresholds in the right ear compared with those of children who did not use headphones. For the entire sample, the hearing thresholds were poorer than those of previous studies, and 50% of the subjects had hearing thresholds $\geq$20 dB HL at one or more frequencies. The overall prevalence of tinnitus was estimated to be 5.3%.

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References

Axelsson A, Aniansson G, Costa O. Hearing loss in school children. A longitudinal study of sensorineural hearing impairment. *Scand Audiol*. 1987;16:137–143.

Bilger RC, Matthies ML, Hammel DR, et al. Genetic implications of gender differences in the prevalence of spontaneous otoacoustic emissions. *J Speech Hear Res*. 1990;33:418–432.

Blandy S, Lutman M. Hearing threshold levels and speech recognition in noise in 7-year-olds. *Int J Audiol*. 2005;44:435–443.

Daud MKM, Noor RM, Rahman NA, et al. The effect of mild hearing loss on academic performance in primary school children. *Int J Pediatr Otorhinolaryngol*. 2010;74:67–70.

Feder K, Marro L, Keith SE, et al. Audiometric thresholds and portable digital audio player user listening habits. *Int J Audiol*. 2013;52:606–616.

Gates GA, Schmid P, Kujawa SG, et al. Longitudinal threshold changes in older men with audiometric notches. *Hear Res*. 2000;141:220–228.

Golz A, Netzer A, Westerman ST, et al. Reading performance in children with otitis media. *Otolaryngol Head Neck Surg*. 2005;132: 495–499.

Golz A, Westerman ST, Westerman LM, et al. Does otitis media in early childhood affect reading performance in later school years? *Otolaryngol Head Neck Surg*. 2006;134:936–939.

Groh D, Pelanova J, Jilek M, et al. Changes in otoacoustic emissions and high-frequency hearing thresholds in children and adolescents. *Hear Res*. 2006;212:90–98.

Haapaniemi JJ. Pure-tone audiometric and impedance measurements in school-aged children in Finland. *Eur Arch Otorhinolaryngol*. 1997;254:269–273.

Haapaniemi JJ. The hearing threshold levels of children at school age. *Ear Hear*. 1996;17:469–477.

Holgers KM, Juul J. The suffering of tinnitus in childhood and adolescence. *Int J Audiol*. 2006;45:267–272.

Holmes AE, Kaplan HS. Screening for hearing loss in adolescents. *Lang Speech Hear Serv Sch*. 1997;28:70.

Holmes AE, Niskar AS, Kieszak SM, et al. Mean and median hearing thresholds among children 6 to 19 years of age: the third national health and nutrition examination survey, 1988 to 1994, United States. *Ear Hear*. 2004;25:397–402.

Hunter LL, Margolis RH, Rykken JR, et al. High frequency hearing loss associated with otitis media. *Ear Hear*. 1996;17:1–11.

International Organization for Standardization: Acoustics. 2010. Audiometric test methods. Part 1: tone air and bone conduction audiometry. (ISO 8253-1:2010).

Jamieson DG, Kranjc G, Yu K, et al. Speech intelligibility of young school-aged children in the presence of real-life classroom noise. *J Am Acad Audiol*. 2004;15: 508–517.

Jerger J. Clinical experience with impedance audiometry. *Arch Otolaryngol*. 1970;92:311–324.

Johansson MS, Arlinger SD. Prevalence of hearing impairment in a population in Sweden. *Int J Audiol*. 2003;42:18–28.

Juul J, Barrenas ML, Holgers KM. Tinnitus and hearing in 7-year-old children. *Arch Dis Child*. 2012;97:28–30.

Kim MG, Hong SM, Shim HJ, et al. Hearing threshold of Korean adolescents associated with the use of personal music players. *Yonsei Med J*. 2009;50:771–776.

Kujawa SG, Liberman MC. Acceleration of age-related hearing loss by early noise exposure: evidence of a misspent youth. *J Neurosci*. 2006;26:2115–2123.

Kumar A, Mathew K, Alexander SA, et al. Output sound pressure levels of personal music systems and their effect on hearing. *Noise Health*. 2009;11:132–140.

Lundquist P. 2003. Classroom noise – exposure and subjective response among pupils. Doctoral dissertation, Umeå University, Department of Public Health and Clinical Medicine, Occupational medicine.

Lundquist P, Holmberg K, Landstrom U. Annoyance and effects on work from environmental noise at school. *Noise Health*. 2000;2:39–46.

Marcoux AM, Feder K, Keith SE, et al. Audiometric thresholds among a Canadian sample of 10 to 17 year old students. *J Acoust Soc Am*. 2012;131:2787–2798.

Muchnik C, Amir N, Shabtai E, et al. Preferred listening levels of personal listening devices in young teenagers: Self reports and physical measurements. *Int J Audiol*. 2012;51:287–293.

Niskar AS, Kieszak SM, Holmes A, et al. Prevalence of hearing loss among children 6 to 19 years of age: the third national health and nutrition examination survey. *JAMA*. 1998;279:1071–1075.

Northern JL, Downs MP. *Hearing in children*. 5th ed. Baltimore: Lippincott Williams & Wilkins; 2002.

Peng JH, Tao ZZ, Huang ZW. Risk of damage to hearing from personal listening devices in young adults. *J Otolaryngol*. 2007;36:181–185.

Rovers MM, Schilder AG, Zielhuis GA, et al. Otitis media. *Lancet*. 2004;363:465–473.

Savastano M. Characteristics of tinnitus in childhood. *Eur J Pediatr*. 2007;166:797–801.

Schilder AG, Snik AF, Straatman H, et al. The effect of otitis media with effusion at preschool age on some aspects of auditory perception at school age. *Ear Hear*. 1994;15:224–231.

Shargorodsky J, Curhan SG, Curhan GC, et al. Change in prevalence of hearing loss in US adolescents. *JAMA*. 2010 304(7), 772–778.

Snihur AWK, Hampson E. Sex and ear differences in spontaneous and click-evoked otoacoustic emissions in young adults. *Brain Cogn*. 2011;77:40–47.

Widen SE, Erlandsson SI. Self-reported tinnitus and noise sensitivity among adolescents in Sweden. *Noise Health*. 2004;7:29–40.