

# Associations between adolescents' earphone usage in noisy environments, hearing loss, and self-reported hearing problems in a nationally representative sample of South Korean middle and high school students

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## Abstract

Few epidemiological studies have examined the relationship between earphone usage and hearing loss in adolescents. This study identified the prevalence of hearing loss in South Korean adolescents using representative national survey data and evaluated the relationship between earphone usage in a noisy environment and hearing loss. This study analyzed 532 subjects (12–19 years) who participated in a 2012 national survey and completed health and noise environment exposure questionnaires and pure tone audiometry (PTA) test. Hearing loss was defined as an average hearing threshold of 26 Decibel-A (dBA) or higher in PTA. The relationship between earphone usage and hearing loss was analyzed using a hierarchical logistic regression model. Adolescents who were exposed to high noise levels via headphones in a noisy environment had a hearing loss prevalence of 22.6% and adolescents who used earphones 80 minutes or more per day on average had the hearing loss prevalence of 22.3%. The results of the logistic regression analysis revealed that adolescents who used earphones in a noisy environment had a 4.5-fold higher risk of hearing loss and an 8.4 times higher risk of having a subjective hearing problem than those who did not use earphones (prevalence odds ratio (pOR)=4.54, 95% confidence interval (CI): 1.35–15.24; pOR=8.39, 95% CI: 1.12–62.83, respectively). Additionally, adolescents who used earphones more than 80 minutes per day in a noisy environment had a 4.7 times higher risk of hearing loss than those who used them less than 80 minutes per day (pOR=4.68, 95% CI: 1.08–20.22). Longitudinal studies are needed to provide evidence of causality between earphone usage and hearing loss.

**Abbreviations:** CI = confidence interval, dBA = Decibel-A, KNHANES = Korea National Health and Nutrition Examination Survey, PMPs = portable media players, pOR = prevalence odds ratio, PTA test = pure tone audiometry test.

**Keywords:** earphone usage, noise environment exposure, noise-induced hearing loss, pure tone audiometry, subjective hearing problem

## 1. Introduction

It has been reported that 1.7% of the world's population is suffering from noise-induced hearing loss,<sup>[1]</sup> and the number of adolescents with this condition is increasing worldwide. In the United States alone, 30 million people were exposed to

environmental noise and 10 million of those exposed were diagnosed with noise-induced hearing loss.<sup>[2]</sup> Noise-induced hearing loss means that auditory cells are permanently damaged from exposure to loud noise over an extended period.<sup>[3]</sup> Noise-induced hearing loss is the second most prevalent type of hearing

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loss after age-related hearing loss (presbycusis). Noise is one of the most common causes of hearing impairment and hearing loss and noise-induced hearing loss is one of the most common occupational diseases in the United States.<sup>[4]</sup> However, hearing impairment has been underestimated compared to other diseases because it generally does not cause much pain,<sup>[5]</sup> it develops gradually,<sup>[5]</sup> and it is not directly associated with mortality. However, noise-induced hearing loss is a very important issue in health science because it affects quality of life.<sup>[6]</sup> Further advances in science and technology may increase the level of noise in everyday life and industrial sites. Therefore, it is expected that the number of patients with noise-induced hearing loss will increase steadily in the future.

Multiple studies have been conducted over the past decade to evaluate treatments for noise-induced hearing loss. These studies show that surgical treatment (e.g., cochlear implants) and aural rehabilitation have limited effects because cochlear hair cells cannot be regenerated once damaged.<sup>[7]</sup> Permanent hearing loss in adolescence can be an obstacle for choosing a career and can decrease quality of life in various ways, such as causing difficulties with learning. It is also highly possible that future elderly populations will suffer from greater hearing loss than they do today if the current adolescents who are at a high risk of noise-induced hearing loss continue with their current behaviors. Therefore, the prevention and early detection of noise-induced hearing loss are important for public health.<sup>[6]</sup> In the United States, the Ministry of Health and Welfare has spent \$700 million on the treatment and rehabilitation of noise-induced hearing loss as of 2009. It is estimated that the social costs will be astronomical when rehabilitation of secondary diseases such as tinnitus associated with noise-induced hearing loss is taken into consideration.<sup>[8]</sup> Noise-induced hearing loss is a preventable disease<sup>[9]</sup>; 50% of noise-induced hearing loss can be prevented through primary prevention.<sup>[10,11]</sup> Preventing health risks from noise exposure and implementing noise reduction measures are critical for reducing the prevalence of noise-induced hearing loss.

Noise-induced hearing loss in young people is mainly caused by listening to loud music.<sup>[12,13]</sup> Several studies<sup>[2,11,14]</sup> have pointed out that 2 of the main risk factors for hearing loss are use of portable audio devices such as iPods and MP3 players and attending concerts or clubs, both of which expose teens to high-intensity music for long periods. In particular, noise exposure from portable audio devices has increased in recent years due to the wide use of smartphones. In Europe, it is estimated that at least 2 million (up to 10 million) adolescents are using MP3 players for more than 1 hour at an excessive volume that can damage their hearing.<sup>[2]</sup> In the US, 1 study found that 12.5% of adolescents between 6 and 19 years old had symptoms of noise-induced hearing loss and 15% of college students complained of hearing loss.<sup>[15]</sup> The same study found that the main cause of such hearing loss was the improper use of portable audio devices.<sup>[15]</sup> Particularly, listening to music in buses or subways where the ambient noise is above 80 Decibel-A (dBA) or the frequent use of portable audio devices while commuting to school are emerging as risk factors of noise-induced hearing loss.<sup>[16,17]</sup>

Many previous studies<sup>[15,18]</sup> have pointed out that adolescents have symptoms such as tinnitus, temporary hearing loss, and noise-induced hearing loss because there is not sufficient education on how to use portable audio devices at reasonable noise levels and moderate lengths of time to protect hearing. Nevertheless, only a few epidemiological studies have evaluated the statistical relationship between earphone usage and the

hearing loss in a cohort of adolescents. The objectives of this study were to

- (1) identify the prevalence of hearing loss among Korean adolescents using representative national survey data,
- (2) analyze the relationship between the use of earphones, noise environment exposure, and subjective hearing problems, and
- (3) provide basic data for educating adolescents about hearing health management and hearing loss prevention.

## 2. Methods

### 2.1. Ethics of human research

The survey conformed to the principles outlined in the Declaration of Helsinki and received clearance from the Institutional Review Board of the Korean Center for Disease Control and Prevention (2010–02CON-21-C, 2013-12EXP-03-5C). The survey procedures were designed to protect participant privacy by allowing anonymous and voluntary participation. Participants were given identification numbers and guaranteed anonymity. After the survey had been fully explained and all participants had provided written informed consent (both directly and from their parents or legal guardians), participants completed a survey.

### 2.2. Subjects

The 2013 Korea National Health and Nutrition Examination Survey (KNHANES) was provided the data for this study.<sup>[19]</sup> The KNHANES is Korea's representative epidemiological survey conducted by the Korea Centers for Disease Control and Prevention in order to calculate reliable statistics on the health status and health behaviors in the Korean population. The KNHANES was conducted using sample data extracted according to the two-stage stratified cluster sampling based on the 2005 Population and Housing Census, a complete enumeration representing Koreans living in local communities. It was conducted between January 2013 and December 2013. Individual responders who were admitted to medical institutions or prisons were excluded from the survey. The provided national epidemiological data is non-identifiable to ensure that individual identities could not be determined from survey data in compliance with the Privacy and Statistics Act. These 740 adolescents who participated in the otolaryngology examination of the 2013 KNHANES were between 12 and 19 years old, were not diagnosed with hearing impairment, and were not wearing an assisting device such as a hearing aid or cochlear implant. The participants completed a health survey, a hearing test, and a noise environment exposure questionnaire. This study analyzed test and survey results from 532 subjects after excluding 208 subjects who did not complete the pure tone audiometry (PTA) test.

## 3. Measurement

### 3.1. Hearing loss and subjective hearing problems

Hearing loss was diagnosed using PTA. PTA was conducted by experienced audiologists in soundproof booths inside a mobile vehicle using an AD229b diagnostic audiometer (Interacoustics, Assen, Denmark). Before conducting PTA, factors affecting hearing (e.g., external ear anomalies, ear wax, the retraction of the tympanic membrane, cholesteatoma, and middle ear effusion)

were recorded. Hearing loss was defined by the following procedure. First, the average hearing thresholds (quartering) of the right and left ears were calculated using the hearing thresholds at 500, 1000, 2000, and 3000 Hz, based on the criteria established by the Committee on Hearing and Equilibrium of the American Academy of Otolaryngology-Head and Neck Surgery.<sup>[20]</sup> The hearing threshold for each frequency was an integer value that was prepared by rounding off the decimal point (e.g., 23.86 dBA is entered as 23 dBA). According to the definition used by the World Health Organization (WHO), people with an average hearing threshold of 24 dBA or less are considered to have “normal” hearing and those with an average threshold of 25 dBA or more are classified as having hearing loss.<sup>[21]</sup> Using these classification criteria, subjects with 1 damaged ear were diagnosed as having unilateral hearing loss, and those with damage in both ears were diagnosed as having bilateral hearing loss. Since the sample size of this study was small (523 subjects) and the study objective was to identify the relationship between noise environment exposure and hearing loss, unilateral or bilateral hearing loss rated as “light” or worse was defined as hearing loss. The subjective hearing problem was binary (good or bad) based on the subject’s response to the question of “Please select the sentence that best describes your hearing.”

### 3.2. Earphone usage habits and noise environment exposure

Noise exposure was investigated using a self-report questionnaire. The experience of using earphones in a noisy environment was divided into 2 types (yes and no) based on the answer to the question, “Have you ever listened to music using earphones in noisy places such as a bus or subway?” The average daily listening time was surveyed for those who responded yes. This study converted this continuous variable to a categorical variable using an optimal category algorithm to determine whether hearing loss significantly increased after subjects were exposed to “earphone usage in a noisy environment” for 80 minutes or more. Based on this result, the average daily listening time was divided into 2 classes (<80 minutes and ≥80 minutes). The noise environment exposure was determined by subjects’ answers to the following questions: exposure to environmental noise for more than 3 months (“Have you ever been exposed to loud noise environments, such as cars, trucks, motorcycles, machinery, or loud music (such as karaoke or theatre) that were so noisy that you had to speak loudly to have a conversation for more than 5 hours per week?”), wearing protective equipment to block the noise in the living environment (“Did you wear a hearing protection device such as earplugs or earmuffs to protect your hearing?”), and momentary noise exposure (e.g., explosion) (“Have you ever been exposed to momentary loud noises such as gunshots or explosions?”). The response to the question about wearing a protective device to protect against the momentary noise was binary (yes or no).

### 3.3. Confounding factors

Age, gender, education level, income, pain, or discomfort due to illness or injury in the past 2 weeks (yes or no), lifetime drinking experience (yes or no), lifetime smoking experience (yes or no), and depression for 2 consecutive weeks (yes or no) were evaluated. Household income levels were classified into 4 quartiles. Education levels were classified as elementary school,

middle school, high school. Lifetime drinking experience examined the experience of drinking more than 1 glass of alcohol until now. Lifetime smoking experience was classified according to WHO criteria<sup>[22]</sup>: people who have smoked less than 5 packs (100 cigarettes) in their lifetime or did not smoke at all were defined as non-smokers and those who have smoked more than 5 packs (100 cigarettes) in their lifetime were defined as smokers.

### 3.4. Statistical analyses

The general characteristics of the subjects were presented as percentages. Differences between groups based on hearing loss and subjective hearing problems were confirmed using the Chi-square test. This study presented prevalence odds ratios (pOR) with a 95% confidence interval (CI) using the hierarchical logistic regression model. There were 3 study models: the crude model did not adjust for confounding factors; model 1 was adjusted for sociodemographic factors (i.e., age, gender, income, and education level); and model 2 was adjusted to consider health factors (smoking, drinking, depression, and pain or discomfort in the past 2 weeks) as well as sociodemographic factors. All analyses were performed using Stata version 13.1 (Stat Corp. Houston, TX) and significance was determined at two-tailed ( $P < .5$ ).

## 4. Results

### 4.1. Characteristics of subjects according to hearing loss and subjective hearing problem

The general characteristics of subjects by hearing loss using PTA and subjective hearing problems are presented in Table 1. The results of the chi-square test showed that hearing loss and subjective hearing problems were significantly affected by the earphone usage in loud environments (defined as an environment where it was hard to communicate) and by length of the mean daily earphone usage time in a loud noise environment ( $P < .05$ ). Adolescents using earphones in a noisy environment had a hearing loss prevalence of 22.6% and a subjective hearing problem rate of 16.6%. Adolescents using earphones in a noisy environment for more than 80 minutes per day on average had a hearing loss prevalence of 22.3% and a subjective hearing problem rate of 16.8%.

### 4.2. Relationship between earphone use habits, noise environment exposure, and hearing loss

The relationships between noise environment exposure, hearing loss, and subjective hearing problems are presented in Table 2. The results of the logistic regression revealed that the use of earphones in a noisy environment (too loud to communicate) and the mean daily earphone usage time in a noisy environment were both significantly related to the prevalence of hearing loss ( $P < .05$ ). Even after adjusting for confounding variables (Model 2), adolescents who used earphones in a noisy environment had a 4.5 times higher risk of hearing loss than those without earphone usage (pOR=4.54; 95% CI: 1.35–15.24). Adolescents who used earphones more than 80 minutes per day in a noisy environment had 4.7 times higher risk of hearing loss than those used earphones less than 80 minutes per day (pOR=4.68; 95% CI: 1.08–20.22). On the other hand, exposure to living environment noise for at least 3 months, wearing equipment to protect against

**Table 1**  
**Characteristics of subjects according to hearing loss and subjective hearing problem, n (%).**

Characteristics	Hearing loss		P	Subjective hearing problem		P
	No (n=421)	Yes (n=111)		No (n=450)	Yes (n=82)	
Age, mean ± SD	15.1 ± 2.2	14.9 ± 2.1	0.149	15.1 ± 2.2	14.7 ± 2.0	0.023
Gender			0.776			0.644
Male	225 (78.7)	61 (21.3)		240 (83.9)	46 (16.1)	
Female	196 (79.7)	50 (20.3)		210 (85.4)	36 (14.6)	
Income (home)			0.724			0.242
1 Quartile	49 (81.7)	11 (18.3)		49 (81.7)	11 (18.3)	
2 Quartile	95 (80.5)	23 (19.5)		98 (83.1)	20 (16.9)	
3 Quartile	122 (80.3)	30 (19.7)		136 (89.5)	16 (10.5)	
4 Quartile	146 (76.4)	45 (23.6)		157 (82.2)	34 (17.8)	
Education levels			0.414			0.426
Elementary school	194 (78.2)	54 (21.8)		207 (83.5)	41 (16.5)	
Middle school	126 (78.3)	35 (21.7)		138 (85.7)	23 (14.3)	
High school	58 (85.3)	10 (14.7)		61 (89.7)	7 (10.3)	
Lifetime smoking experience			0.879			0.493
No	285 (79.2)	75 (20.8)		308 (85.6)	52 (14.4)	
Yes	58 (78.4)	16 (21.6)		61 (82.4)	13 (17.6)	
Lifetime drinking experience			0.138			0.553
No	235 (77.3)	69 (22.7)		257 (84.5)	47 (15.5)	
Yes	142 (83.0)	29 (17.0)		148 (86.5)	23 (13.5)	
Depression			0.827			0.161
No	345 (79.5)	89 (20.5)		367 (84.6)	67 (15.4)	
Yes	32 (78.0)	9 (22.0)		38 (92.7)	3 (7.3)	
Pain or discomfort due to illness or injury in recent 2wk			0.953			0.113
No	342 (79.2)	90 (20.8)		364 (84.3)	68 (15.7)	
Yes	35 (79.5)	9 (20.5)		41 (93.2)	3 (6.8)	
Experience of using earphones in a noisy environment			0.004			0.006
No	57 (93.4)	4 (6.6)		59 (96.7)	2 (3.3)	
Yes	363 (77.4)	106 (22.6)		391 (83.4)	78 (16.6)	
Mean daily earphone usage			0.006			0.004
<80 min	41 (95.3)	2 (4.7)		43 (100)	0	
≥80 min	380 (77.7)	109 (22.3)		407 (83.2)	82 (16.8)	
Exposed to the noise of living environment ≥3 mo			0.871			0.302
No	356 (79.3)	93 (20.7)		384 (85.5)	65 (14.5)	
Yes	62 (78.5)	17 (21.5)		64 (81.0)	15 (19.0)	
Wearing protective equipment in noise of living environment			0.269			0.391
No	47 (75.8)	15 (24.2)		49 (79.0)	13 (21.0)	
Yes	15 (88.2)	2 (11.8)		15 (88.2)	2 (11.8)	
Momentary exposure to noise such as explosion			0.206			0.471
No	332 (80.4)	81 (19.6)		353 (85.5)	60 (14.5)	
Yes	87 (75.0)	29 (25.0)		96 (82.8)	20 (17.2)	
Wearing protective equipment in momentary noise			0.889			0.692
No	71 (74.7)	24 (25.3)		78 (82.1)	17 (17.9)	
Yes	16 (76.2)	5 (23.8)		18 (85.7)	3 (14.3)	

Any subjects with missing values are excluded from the analysis.

living environment noise, and exposure to a momentary loud noise such as explosion were not significantly associated with hearing loss.

#### 4.3. Relationship between earphone usage habits, exposure to noisy environments, and subjective hearing problems

The results of the logistic regression analysis (Table 3) showed that earphone usage in a noisy environment was significantly related to subjective hearing problems ( $P < .05$ ). Even after adjusting for all confounding variables (Model 2), adolescents who used earphones in a noisy environment had 8.4 times higher risk of subjective hearing problems than those who did not use earphones (pOR = 8.39; 95% CI: 1.12–62.83). Since none of the

adolescents who used earphones less for than 80 minutes reported hearing problems, the relationship between earphone usage time and subjective hearing problems was not calculated.

The results of the logistic regression analysis showed that use of equipment for protecting against living environment noise was not related to hearing loss and subjective hearing problem (Tables 4 and 5).

## 5. Discussion

Excessive noise has emerged as a significant problem in modern society, and it is important to prevent hearing loss due to noise exposure. In this study, adolescents who responded that they used earphones when in a noisy environment were found to have a hearing loss prevalence of 22.6% by PTA, and 16.6% of these subjects subjectively reported hearing problem rate. Rhee et al<sup>[23]</sup>



**Table 2**  
**Relationship among earphone use habits and hearing loss, hierarchical logistic regression model: pOR (95% CI).**

Characteristics	Crude model	Model 1	Model 2
Experience of using earphones in a noisy environment			
No	1	1	1
Yes	4.16 (1.47, 11.73)**	4.82 (1.46, 15.89)**	4.54 (1.35, 15.24)*
Mean daily earphone usage			
<80 min	1	1	1
≥80 min	5.88 (1.40, 24.70)*	5.18 (1.21, 22.02)*	4.68 (1.08, 20.22)*
Exposed to the noise of living environment ≥3 mo			
No	1	1	1
Yes	0.95 (0.53, 1.70)	0.87 (0.47, 1.63)	0.80 (0.42, 1.51)
Momentary exposure to noise such as explosion			
No	1	1	1
Yes	0.73 (0.45, 1.18)	0.69 (0.41, 1.17)	0.62 (0.36, 1.05)

Model 1 was adjusted with age, gender, income, and education level; Model 2 was additionally adjusted with smoking, drinking, depression, and pain or discomfort over the past 2wk. CI=confidence interval, pOR=prevalence odds ratio.

\*  $P < .05$ .  
 \*\*  $P < .01$ .

evaluated the prevalence of noise-induced hearing loss in 2879 middle and high school students (13–19 years old) by conducting PTA, using frequency, and speech audiometry to evaluate listening comprehension in daily communication. They found that 17.2% of subjects had noise-induced hearing loss, similar to the results of our study. The US National Health and Nutrition Examination Survey also reported a hearing loss prevalence of 19.5% as of 2006.<sup>[24]</sup> These prevalence rates mean that 1 in every 5 Korean and American adolescents has hearing loss. The National Health Insurance Corporation<sup>[25]</sup> showed that the number of patients with hearing loss increased by more than 25% over 5 years (from 277,000 in 2012 to 349,000 in 2017), a 4.8% annual increase. Moreover, it was found that adolescents between 15 and 19 years old had the largest increase in hearing loss among all age classes. Therefore, countermeasures at the national level are urgently needed to reduce the prevalence of adolescent hearing loss.

**Table 3**  
**Relationship between earphone usage habits in a noisy environment and reporting of subjective hearing problems, hierarchical logistic regression model: pOR (95% CI).**

Characteristics	Crude model	Model 1	Model 2
Earphone use			
No	1	1	1
Yes	5.88 (1.40, 24.59)*	9.24 (1.25, 68.38)*	8.39 (1.12, 62.83)*
Mean daily earphone usage in a noisy environment			
<80 min	1	1	1
≥80 min	Na	Na	Na
Exposed to the noise of living environment ≥3 mo			
No	1	1	1
Yes	0.72 (0.38, 1.34)	0.68 (0.34, 1.32)	0.71 (0.35, 1.44)
Momentary exposure to noise such as explosion			
No	1	1	1
Yes	0.81 (0.46, 1.42)	0.81 (0.44, 1.50)	0.87 (0.45, 1.67)

Model 1 was adjusted with age, gender, income, and education level; Model 2 was additionally adjusted with smoking, drinking, depression, and pain or discomfort over the past 2wk. CI=confidence interval, pOR=prevalence odds ratio.

\*  $P < .05$ .

**Table 4**  
**Relationship between hearing loss and the use of equipment for protecting against living environment noise, hierarchical logistic regression model: pOR (95% CI).**

Characteristics	Crude model	Model 1	Model 2
Noise of living environment			
No	1	1	1
Yes	2.39 (0.49, 11.68)	1.70 (0.29, 9.82)	1.67 (0.22, 12.36)
Momentary noise			
No	1	1	1
Yes	1.08 (0.35, 3.26)	1.15 (0.30, 4.41)	1.02 (0.23, 4.44)

Model 1 was adjusted with age, gender, income, and education level; Model 2 was additionally adjusted with smoking, drinking, depression, and pain or discomfort over the past 2wk. CI=confidence interval, pOR=prevalence odds ratio.

The results of this study indicate that adolescents who listen to loud music using earphones in an already noisy environment or who used earphones for more than 80 minutes per day on average in a noisy environment had a significantly higher risk of hearing loss. Similar to our results, another study found that using earphones for more than 60 minutes per day on average was related to hearing loss in Korean university students.<sup>[18]</sup> Moreover, Kim<sup>[26]</sup> evaluated the relationship between earphone usage and hearing loss in high school students using survey data and found that 52% of high school students who used earphones for more than 1 hour per day subjectively reported hearing deterioration and 84.5% of these students had pain or tinnitus. South Korean adolescents use portable audio devices longer than American adolescents. It has been reported that 24% to 27% of American adolescents listened to music using portable audio devices,<sup>[27–29]</sup> while 94.3% of South Korean adolescents used portable audio devices for 1 to 3 hours per day for more than 3 years.<sup>[30]</sup>

Earphones are tight-fitting portable speakers that can be used while moving without being disturbed by ambient noise. Although they are widely used by adolescents around the world, they pose a high risk of noise-induced hearing loss when people are exposed to excessively loud volume for a long time.<sup>[31,32]</sup> People are more likely to listen to music at a louder volume than environmental noise especially in subways and buses where the average noise level is 80dB. Park et al<sup>[33]</sup> examined the sound pressure of earphone listening according to noise environments using healthy adult subjects with normal hearing. They reported

**Table 5**  
**Relationship between subjective hearing problem awareness and the use of equipment for protecting against living environment noise, hierarchical logistic regression model, hierarchical logistic regression model: pOR (95% CI).**

Characteristics	Crude model	Model 1	Model 2
Noise of living environment			
No	1	1	1
Yes	1.99 (0.40, 9.82)	0.86 (0.14, 5.24)	1.25 (0.10, 15.04)
Momentary noise			
No	1	1	1
Yes	1.30 (0.34, 4.94)	2.12 (0.39, 11.56)	1.15 (0.19, 6.99)

Model 1 was adjusted with age, gender, income, and education level; Model 2 was additionally adjusted with smoking, drinking, depression, and pain or discomfort over the past 2wk. CI=confidence interval, pOR=prevalence odds ratio.

that the average listening sound pressure was 74 dBA when listening to music with earphones in a quiet environment and it increased to 84 dB, approximately 10 dBA increase, in a noisy environment.<sup>[33]</sup> When listening to music with earphones, the sound from the audio device should be louder than surrounding noise to clearly hear the music, so that the surrounding noise level increases the listening volume. In other words, the masking effect, which increases the sound pressure level of portable audio equipment in a noisy environment because the noise raises the audible limit, is a major risk factor of noise-induced hearing loss.<sup>[34]</sup> Hong et al<sup>[35]</sup> examined hearing loss in 1658 South Korean adolescents aged between 13 and 18 years old after classifying environmental noise levels into occupational, non-occupational, and momentary noise and reported that listening to music in a noisy place using earphones was closely associated with high-frequency hearing loss. Despite this risk, a large number of adolescents use earphones in noisy environments. Rudzyn and Fisher<sup>[36]</sup> studied the relationship between the use of portable media players (PMPs) and noise-induced hearing loss in 2143 German adolescents. They found that 85% of the subjects used PMPs and 3 out of 10 subjects had hearing pressures above 80 dBA. In addition, the earphone listening sound pressure through for most South Korean adolescents (58.2%) exceeds the currently recommended total amount of daily noise listening.<sup>[36]</sup> Therefore, health education on safe volume levels for earphones is needed for adolescents.

The mechanism by which how loud noise can induce hearing loss is through damage to the cochlear hair cells. Cochlear hair cells vibrate in response to external sound stimuli. They are the most vulnerable cells in the cochlea and the first cells to be damaged by loud noise.<sup>[36]</sup> When loud noise occurs, it first causes the fracture and distortion of the stereocilia, which reduces the transmission of the shearing force. Thereby, the tip link between the stereocilia is broken, which causes problems with mechano-transduction.<sup>[37]</sup> If one is exposed to loud earphone noise for an extended period of time, the inner ear can become fatigued and the auditory nerve can become insensitive, which induces temporary noise-induced hearing loss. In a severe case, exposure to loud noise increases the risk of causing a permanent hearing loss.<sup>[38,39]</sup> Nevertheless, studies have found that frequently listen to MP3 players at maximum volume<sup>[40]</sup> and that even college students were not fully aware of the risk of noise exposure (e.g., loud music).<sup>[41]</sup> Since hearing loss is not distinct in the initial stage and gradually progresses over 10 years, health education should be targeted to adolescents when they begin to be exposed to portable audio devices.<sup>[38]</sup>

When playing music, the listener can change the device (e.g., speakers or headphones) and exposure level (e.g., duration and intensity) voluntarily, unlike noise exposure in a workplace. Therefore, learning how to safely use portable audio equipment including smartphones is essential for adolescents to prevent noise-induced hearing loss. It is important to evaluate adolescents' understanding of hearing loss and hearing protection and provide appropriate education so that they can maintain healthy hearing, which is hard to recover once it is damaged. Many countries have set sound pressure levels that are acceptable for adults. For example, the EU recommends not being exposed to 85 dBA noise levels for more than 8 hours a day or 40 hours per week.<sup>[42]</sup> In Europe, noise exposure from portable audio devices and cell phones with portable audio function was newly defined as a health risk in 2013, and it is recommended to keep the maximum volume below 90 dBA.<sup>[42]</sup> On the other hand, South

Korea does not have proper guidelines for adolescents regarding noise exposure from cell phones with music play functions. In order to prevent noise-induced hearing loss, it is necessary to develop and enact guidelines and education programs that can enhance knowledge about the proper use of earphones in adolescents and help to change their attitudes about earphone use.

This study provides evidence of a relationship between noise exposure and hearing loss in adolescents using epidemiological data from the Korean national health survey. Several limitations of this study are as follows. First, this study was a cross-sectional study that found statistical associations between excessive earphone use and hearing loss, but these associations cannot be interpreted as causal relationships. Therefore, longitudinal studies are needed to determine the causal mechanisms involved. Second, this study could not consider medication use (e.g., aminoglycoside, cisplatin, and furosemide, which might affect hearing loss) as a confounding variable because the data was not available. Third, some variables (e.g., high school students reporting subjective hearing problems) were identified in a small group of subjects. Fourth, it was not possible to quantify the noise exposure level because the data were obtained solely through questionnaires as national epidemiological data. Future studies are needed to evaluate prospective cohorts measuring noise exposure quantitatively.

## 6. Conclusions

This epidemiologic study found that listening to music using earphones for 80 minutes or longer in a noisy environment was a risk factor for hearing loss. Noise-induced hearing loss should be managed from a public health perspective, not limited to personal health care. Therefore, it is necessary to develop guidelines for educating adolescents about safe earphone usage and for protecting their hearing from noise environments. Furthermore, based on the results of this study, longitudinal epidemiological studies are needed to further explore the mechanism by which earphone use causes hearing loss.

## Author contributions

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