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Occupational and Nonoccupational Noise Exposure over 24hr/7day among Underserved Occupations

관리 취약 직업군의 24 시간 / 7 일간 직업 및 비직업적 소음 노출평가

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Abstract

Occupational and Nonoccupational Noise Exposure over 24hr/7day among Underserved Occupations

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The World Health Organization (WHO) has stated that hearing loss is one of the top ten health problems worldwide, and that noise induced hearing loss (NIHL) is the leading occupational disease. The true prevalence of NIHL may be higher than expected because of the small proportion of occupations assessed and under-reporting. Coverage of risk assessment should increase to determine the true prevalence of NIHL. In the same context, the new Noise Directive 2003/10/EC went into effect in 2006. The EU emphasized that noise exposure assessments should cover all sectors and lowered the noise exposure limit. Occupational health research and services in Korea are still concentrated in the manufacturing sector.

The purposes of this study were to assess the occupational noise exposure of underserved occupations, as well as their nonoccupational activities, which

have been excluded from previous studies. Construction workers, firefighters, musicians, service workers, office workers, housewives, and students were selected as underserved occupations. Although construction workers, musicians, firefighters, and service workers are exposed to occupational noise, an assessment of noise exposure among them has rarely been conducted. Office workers, housewives, and students are not thought to be adversely affected by noise. However, an occupational noise exposure limit was established on the assumption that nonoccupational noise exposure could be ignored; however, that needs verification because environmental noise continues to grow in extent, frequency, and severity as a result of population growth, urbanization, and technological developments.

· **Assessment of apartment construction worker noise exposure**

A noise exposure assessment was performed for 139 construction workers from 10 construction trades working at 53 apartment construction sites located in the northern part of Gyeonggi-do. The mean L_{MOEL} for 139 dosimeter samples was 87.8 ± 4.3 dBA. The mean noise exposure level of each construction trade (trade mean) was calculated. Significant differences were observed between construction trades. The highest L_{MOEL} values were measured for concrete chippers (93.2 ± 2.6 dBA), followed by ironworkers (88.4 ± 0.7 dBA), concrete finishers (88.3 ± 2.7 dBA), masonry workers (87.7 ± 1.9 dBA), pile driver operators (85.6 ± 1.7 dBA), concrete carpenters (84.9 ± 2.4 dBA), interior carpenters (83.5 ± 2.1 dBA), and other groups (81.4 ± 2.2 dBA). These results indicate that almost all construction workers in this study are at risk of NIHL, and that construction trades are a useful exposure metric at apartment construction sites.

· **Assessment of noise measurements made with continuous monitoring over time (24 hours/7 days) among underserved occupations**

The average $L_{eq\ 24hr,w}$ among 47 individuals in the underserved occupations was 74 dBA (range, 64-96 dBA). The average $L_{eq\ 24hr,w}$ was highest for Korean traditional music apprentices, followed by heavy equipment operators, firefighters, service workers, office workers, industrial hygienists, graduate and undergraduate students, and housewives (89, 77, 76, 76, 75, 71, 71, and 71 dBA, respectively, $p < 0.001$). A total of 38 (80.9%) were exposed to noise levels > 70 dBA, which corresponds to the WHO exposure limit. Additionally, 60% (15 of 24) of the participants with occupations thought to have low noise exposure (office workers, housewives, and students) were over the recommended limit.

Furthermore, the mean nonoccupational noise exposure level of all participants (72 ± 6 dBA) that normalized to a nominal 24h was over the recommended limit; thus, nonoccupational noise exposure may not be negligible.

· **Task-specific noise exposure assessment of firefighters**

The firefighter noise-sample datasets revealed that most firefighters are exposed to higher than recommended exposures at a low-action value of $L_{ep,d}$ (shift-adjusted daily personal noise exposure level) = 80 dBA. The highest mean level of noise exposure was for rescuers (84.6 ± 6.2 dBA), followed by drivers (83.3 ± 2.7 dBA) and suppressors (79.5 ± 3.5 dBA). Noise measurements were combined with time-at-task information to concentrate on noise exposure, which showed that 82.3% of sound exposure occurred while checking equipment and responding to fire or emergency calls. This information can be obtained only through a task-specific noise exposure assessment, which is useful for controlling noise.

· **Hearing among male firefighters: A comparison with hearing data from screened and unscreened male population**

A comparison of firefighter hearing threshold levels (HTLs) with those of an otologically normal male Korean population (KONP) and non-industrial noise-exposed male Korean population (KNINEP) by age and frequency showed that the firefighter HTLs were significantly increased (poorer hearing) across most

age groups and frequencies compared with those of the KONP. The firefighter HTLs were worse in the younger age groups (< 45 years) but not different in the older age groups (> 45 years) compared with those of the KNINEP. The firefighter age-adjusted HTLs were significantly worse than those of the KONP (prevalence ratio [PR] = 5.29, $p < 0.001$), but not different from those of the KNINEP (PR = 0.99, $p = 0.550$). Rescuers (PR = 1.006, $p < 0.001$) had worse hearing than the unscreened general population after adjusting for age. The noise exposure assessments showed that some firefighters were at risk for NIHL, consistent with the results of the HTL comparisons.

In brief, the underserved occupations assessed in this study, including construction workers, Korean traditional music apprentices, and firefighters, are almost at risk of NIHL. The hearing levels of younger firefighters and rescuers were worse than expected by normal age alone. These data indicate the need for a comprehensive assessment and noise reduction efforts in these occupational groups. The general assumption that housewives, students, and office workers are exposed to negligible noise may be incorrect. Nonoccupational noise exposure should be considered when assessing noise health hazards.

Key words : noise, noise exposure assessment, noise induced hearing loss, underserved occupations, 24 hour, nonoccupational

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Abbreviations

ACGIH	The American Conference of Governmental Industrial Hygienists
ANSI	American National Standards Institute, Inc.
ASA	Acoustical Society of America
CFR	Code of Federal Regulations
dB	decibel
dBA	decibel measured using A frequency-weighting
dBC	decibel measured using C frequency-weighting
EPA	Environmental Protection Agency (US)
ER	exchange rate. Unit : dB per time doubling
EU	European Union
HCP	hearing conservation program
HPD	hearing protection device
HTL	hearing threshold level. Unit : dB
HWE	healthy worker effect
IACI	industrial accident compensation insurance
IRB	institutional review board
ISO	International Organization for Standardization
KOEL	Korea Occupational Exposure Limit.
KONP	Otologically Normal Male Korean Population
KNINEP	Non-industrial Noise-exposed Male Korean Population
KNAHNES	Korean National Health and Nutrition Examination Survey
KNSO	Korea National Statistics Office
LEAV	Lower Exposure Action Values
$\mathbf{L_{eq,T}}$	equivalent continuous sound pressure level, during time period T using a 3dB exchange rate and no threshold.

$L_{eq,activity}$	task-specific Leq values or Leq during a specific task(activity)
$L_{eq,ME}$	weekly personal noise exposure levels in the microenvironment
$L_{eq\ O,w}$	occupational noise L_{eq} for a week
$L_{eq\ NO,w}$	nonoccupational noise L_{eq} for a week
$L_{eq24hr,d}$	daily noise exposure level. L_{eq} during a day (24 hr). WHO recommended it to be lower than 70 dBA for hearing safety. See $L_{eq,T}$
$L_{eq24hr,w}$	L_{eq} during a week, which was calculated to using logarithmic averaging (energy averaging) $L_{eq24hr,d}$s for a week. See $L_{eq,T}$
$L_{eq,6760hr}$	nonoccupational noise exposure level for 1 year. See $L_{eq,T}$
$L_{eq,8760hr}$	noise exposure level for 1 year. See $L_{eq,T}$
$L_{ep,d}$	(shift-adjusted) daily personal noise exposure level, which is corresponds to $L_{ex,8h}$
$L_{ep,w}$	weekly noise exposure level, which is corresponds to Lex,8h
$L_{ex,8h}$	noise exposure level normalized to a nominal 8 h working day, defined in International Standard ISO 1999.
L_{OSHA}	A-weighted average sound level, with 5 dB exchange rate and slow response, applied in OSHA. Unit : dBA
L_{MOEL}	A-weighted average sound level, with 5 dB exchange rate, threshold=80 dB and slow response, applied in MOEL. Unit : dBA
L_{NIOSH}	A-weighted average sound level, with 3dB exchange rate, threshold=80 dB and slow response, applied in NIOSH. Unit : dBA
ME	microenvironment
MOEL	Ministry of Employment and Labor (Republic of Korea)
NIHL	noise induced hearing loss. Unit : dB
NIOSH	National Institute for Occupational Safety and Health (US)
NIPTS	noise induced permanent threshold shift
OSHA	Occupational Safety and Health Administration (US)
Pa	Pascal (=N/m^2)
P_{peak}	peak sound level with C-weighting or unweighted in decibels referenced to 20 micropascals, which is the maximum sound level during a given time interval when the normal frequency and time weighting is not used. This descriptor can be expressed as L_{cpk} or L_{pk}

PR prevalence ratio

P_{ref} Reference sound pressure (20 μPa)

PTA pure-tone average. PTA1234 indicated arithmetic mean of hearing threshold level at 1, 2, 3, 4 kHz from audiometric test. PTA 46, PTA345 and PTA5124 stand for mean of HTLs in the same manner. Unit : dB

PTS permanent threshold shift

PEL permissible exposure limit. A-weighted sound level at which exposure for a stated time, typically 8 hrs, accumulates 100% noise dose. Unit: dBA

REL Recommended exposure limit. NIOSH recommended 8-hr time-weighted average limit (85 dB), using a 3dB exchange rate.
Unit : dBA

SCBA self-contained breathing apparatus

SE sound exposure, which is used as the same with E_A term (A-weighted sound exposure) computed with 3-dB exchange rate in ISO 1999.

$$SE = (p_{ref}^2 T) \times 10^{\frac{L_{eq},T}{10}} Pa^2 hr, \quad p_{ref} = 20\mu Pa$$

SES socioeconomic status

SPL sound pressure level. Unit : dB

TAD time-activity diary

TB task-based. A type of exposure assessment, which requires the assessor to split the work of each kind of job or trade into tasks.

TM trade*-mean, A type of exposure assessment, which requires the assessor to perform full shift measurement for job or trade. (*Trade indicates subgroups with different professional skills)

TLV® threshold limit value

TTS temporary threshold shift. Unit : dB

TWA A-weighted average sound level with 5 dB exchange

UEAV upper exposure action value ($L_{ep,d}$=85 dBA and P_{peak}=140 Pa) in the Control of Noise at Work Regulations UK 2005 by EU directive 2003/10/EC

WHO World Health Organization

Chapter 1.

Introduction

This chapter was presented in Korea Industrial Hygiene Association Conference (2013.10.25)

1.1. Background

The World Health Organization (WHO) has stated that hearing loss is one of the top 10 health problems worldwide and that noise induced hearing loss (NIHL) is the leading occupational disease. The true prevalence of the NIHL may be higher than expected because of small portion of occupations assessed and under-reporting. To get closer true prevalence of NIHL, the coverage of risk assessment should increase. In the same context, we can understand the new Noise Directive 2003/10/EC, which went into effect in 2006. EU emphasized that noise exposure assessment should cover all sectors and lowered the noise exposure limit. On the other hand, in Korea, occupational health research and service are still concentrated in the manufacturing sector.

European Union new noise directive and its implications

Since 2006, the European Union (EU) Directive 2003/10/EC has been implemented in most European community countries. The new occupational noise regulations apply to all sectors not specifically excluded, such as maritime navigation, air transport, the military community, and the music and entertainment sector. As an example, employers in the music and entertainment sector must assess the noise risk to musicians, vocalists, and bar staff.[1] In the workplace, it is time for the cliché “noise is unwanted sound” to disappear. On the other hand, in Korea, occupational health services—including noise exposure assessment and related screening tests—are still concentrated in the manufacturing sector.

Table 1-1. Noise exposure, health examination and NIHL by sector in Korea (2010)

Industry Sector	No. of employed persons [a]	% of noise exposed person [b]	No. of noise exposed persons [c]	No. of health examination for noise (%) [d]	No. of suspicious NIHL [e]
Agriculture, forestry and fishing	1,231,000	13.5	166,185	333 (0.20)	3 (0.90)
Mining and quarrying	26,000	68.1	17,706	2365 (13.36)	153 (6.47)
Manufacturing	4,156,000	44.0	1,828,640	412807 (22.57)	3957 (0.96)
Electricity, gas, steam and water supply	77,000	33.7	25,949	7904 (30.46)	35 (0.44)
Sewage, waste management, materials recovery and etc.	69,000	33.7	23,253	1414 (6.08)	17 (1.20)
Construction	1,726,000	56.0	966,560	32073 (3.32)	539 (1.68)
Wholesale and retail trade	3,589,000	13.7	491,693	7945 (1.62)	68 (0.86)
Transportation	1,283,000	28.1	360,523	7438 (2.06)	24 (0.32)
Accommodation and food service activities	1,900,000	24.1	457,900	353 (0.08)	4 (1.13)
Information and communications	701,000	9.7	67,997	2455 (3.61)	7 (0.29)
Financial and insurance activities	810,000	4.2	34,020	37 (0.11)	0
Real estate activities and renting and leasing	505,000	10.3	52,015	984 (1.89)	8 (0.81)
Professional, scientific and technical activities	932,000	3.4	31,688	2583 (8.15)	14 (0.54)
Business facilities management and business	1,024,000	17.8	182,272	16521 (9.06)	110 (0.67)
Public administration and defence ; compulsory social security	930,000	14.0	130,200	5220 (4.01)	6 (0.11)
Education	1,722,000	15.9	273,798	40 (0.01)	1 (2.50)
Human health and social work activities	1,219,000	8.9	108,491	2025 (1.87)	12 (0.59)
Arts, sports and recreation related services	395,000	31.2	123,240	149 (0.12)	0
Membership organizations, repair and other personal services	1,223,000	25.7	314,311	14172 (4.51)	119 (0.84)
Activities of households as employers; undifferentiated goods	151,000	2.8	4,228	10 (0.24)	0
Activities of extraterritorial organizations and bodies	17,000	0.0	-	-	0
Total	23,686,000	23.9	5,660,669	517	5077

No., number [a] Economically active population (2010.12), Korea National Statistics Office(KNSO) [b] Korea Working Condition Survey (2010) [c] No. of employed persons × % of noise exposed persons, [d] Annual Report of Work's Health Examination(2010), No. of health examination for noise÷No. of noise exposed persons (%), [e] Annual Report of Work's Health Examination(2010)

In Korea, 23.9% of workers surveyed reported that they are exposed to occupational noise loud enough to raise their voices to hold a conversation with colleagues at least one-fourth of their working time (corresponding to 85 ~ 90 dBA).[2] As shown in Table 1-1, workers in various sectors, including construction, mining, and manufacturing, are exposed to noise. However, to date, occupational health services including exposure assessment have focused mainly on the manufacturing and mining industries. Only 3.3% of noise-exposed construction workers underwent an audiometric test despite the fact that construction is the second most common industry comprising noise-exposed workers (after mining), according to the 2010 Korea Working Condition Survey. [2 3] The probability of discovering noise induced hearing loss (NIHL) through a medical examination is higher in the construction sector than in the manufacturing sector (1.68% vs. 0.96%, respectively).[3] Assessment of noise exposure among construction workers is rarely conducted,[4-6] but must be carried out prior to audiometric testing.[7] Moreover, in the arts, sports, and recreation services sector; transportation sector; and accommodation and food service activities sector, a low proportion of noise-exposed workers underwent worker's health examinations (0.12%, 2.06%, and 0.08%, respectively) despite the fact that more than 20% of their workers were exposed to loud noise every day (31.2%, 28.1%, and 24.1%, respectively). Noise exposure assessment for workers in these sectors has been conducted in Korea only rarely. In the education sector and public administration and defense sector, in which the white-collar is dominant, more than 10% of workers are exposed to noise and are used as control groups (non-exposed groups) of cross-sectional studies because they are not thought to be exposed to occupational noise. [2 3 5 6]

In an analysis of the noise exposure assessment coverage and NIHL detection rate in 20 countries in the EU, Paek (2007)[8] reported that as noise assessment coverage increases, the number of patients with NIHL increases. In turn, as the number of patients with NIHL increases, the proportion of the noise-exposed population decreases. The coverage of noise exposure assessment in Korea has not changed substantially during the last 10 years, nor has there been a significant change in the rate of working places exceeding noise limits.[4 6 9] During the same period, the number of patients with hearing loss compensated by the Industrial Accident Compensation Insurance (IACI) Act has been relatively constant at around 200 to 300 persons annually, and the number of patients suspected to have NIHL has been stagnant, at between 2000 and 4000 annually, since 2002.[9] In addition, the proportion of noise-exposed workers in 2010 was almost identical to that in 2006 (23.9% and 21.8%, respectively).[2 10] Therefore, occupational health and safety services in Korea have been ineffective in managing NIHL.

In the same context, we can understand the new Noise Directive 2003/10/EC, which went into effect in 2006. This Directive is a revised version of the earlier Directive 86/188/EEC and is the 17th individual Directive within the meaning of Directive 89/391/EEC, which lays down minimum requirements for the protection of workers from occupational risks. In a nutshell, the difference between the Directive 86/188/EEC and the Directive 2003/10/EC is the widening of the scope of sector and the occupational noise exposure limits. The new Directive applies to all sectors, including maritime navigation and air transport, which were excluded from the Directive 86/188/EEC. This new directive pays special attention to workers from the music and entertainment sectors; for effective application to the music and entertainment sector, it provides practical guidance and a 2-year transitional period. In addition, new threshold values for noise exposure have been established, which are lower and more protective than the previous values. The exposure limit was reduced from 90 to 87 dBA, which is defined as the maximum allowable daily noise exposure level at the worker's ear, taking all protective measures into consideration. Table 1-2 shows the difference between the new and old Directives. The change from 85 to 80 dB in the action level is significant and noticeable because it indicates a more than twofold reduction in sound energy. More attention should be paid to impulsive noise in this new Directive. Weekly noise monitoring is recommended as adequate in the case of high daily noise exposure variation (for more detail, see Table 1-2). [1 11 12]

Table 1-2. Comparison between Directive 86/188/EEC and 2003/10/EC

Item	Directive 86/188/EEC	Directive 2003/10/EC
Scope of Application Sector	Maritime and air transport sectors excluded	All sectors (music and entertainment sectors after two-year transitional period)
The principle of noise reduction	The lowest level reasonably practicable , taking account of technical progress and the availability	Risk assessment approach by Framework Directive 89/391/EEC Avoiding is the top priority Competent assessment by representative sampling (weekly based etc.)
Occupational exposure limits and action values	Action level : 85 dBA Exposure limit : 90 dBA or P_{peak}=200 Pa	Lower Exposure Action Value : 80 dBA and P_{peak}=112 Pascal Upper Exposure Action Value : 85 dBA and 140 P_{peak}= Pascal Exposure Limit Value : 87 dBA and P_{peak}=200 Pascal
Noise level that HPD make available	85 dBA	80 dBA
Noise level that HPD shall be used	90 dBA	85 dBA
Noise level that workers receive information and training	85 dBA	80 dBA
Noise level reaching the ear should be below	-	87 dBA
Noise level that employ shall establish reduction program	90 dBA	85 dBA

EEC, European Economic Community; EC, European Community; HPD, hearing protective device; P_{peak}, peak sound level

Assessing the risk of NIHL

The new lowered exposure action value of 80 dBA in EC Directive 2003/10/EC from 85 dBA in old one is in accordance with the ISO-1999 noise exposure–hearing effect database (Table 1-3).[13 14] As shown in the table 1-3, ISO-1999 described that occupational noise exposure below 80 dB is associated with a "nil/negligible" health risk. This standard also provides the basis of the occupational noise exposure limits, including the relationship of time-intensity trading and the setting of continuous noise with impulsive noise (Table 1-4). National Institute for Occupational Safety and Health (NIOSH), and Environmental Protection Agency (EPA) in the US, have developed standard protocols for integrating continuous noise levels over exposure duration. [15 16] Although EPA and NIOSH established the risk of noise as somewhat higher than that of ISO-1999, the level adopted by the enforcement authority US OSHA has been 90 dBA since 1971. To make matters worse, OSHA has used an exchange rate of 5 dBA instead of the 3 dB exchange rate adopted by ISO; this rate represents the decrease in noise level that is allowed for every doubling of duration with the same effect on permanent hearing threshold shift.[13 17] The 3 dB exchange rate, which is based on the "equal energy" rule (an equal amount of sound energy will result in an equal permanent hearing threshold shift, irrespective of the distribution of energy across time), is supported by almost all scientists. It is obvious that the change of the exchange rate to 3 dBA by OSHA will increase the number of workers that exceed the exposure limit and develop NIHL. Korea's occupational noise exposure limit is similar to that of OSHA permissible exposure limit (PEL) but provides less protection for workers because noise control is less mandatory. Social acceptability of NIHL and noise in Korea and the US did not exceed the status of 1990, when a revised version of ISO-1999 was signed by worldwide professionals.

That exposure limits are different from country to country may be one reason that NIHL has been termed "sociocusis." Although it is not compulsory, the US EPA recommended a high protective noise exposure level as a $L_{eq\ 24hr}$ of 70 dBA in 1974, providing an adequate noise safety margin against noise induced permanent threshold shift (NIPTS). The EPA estimated that to protect virtually the entire population from any significant NIPTS, noise exposure should be limited to an $L_{eq\ 24\ hr}$ of 70 dB, which was confirmed by the WHO in 1998. [15 18] ISO-1999 has been available for more than 20 years. This standard is well accepted—albeit not universally—and is the most stringent standard internationally. It presents the distributions of permanent threshold shifts (PTS) associated with specified noise exposures and durations, along with a model for combining noise induced and age-related portions to predict the PTS distributions for noise-exposed populations. However, it has some limitations, some of which are noted in the published standards and that are mainly related to its assumption about the characteristics of tested subjects. As time goes by and more research data become available, the assumption will need to be corrected. It was first assumed that nonoccupational hearing loss is negligible.

Since 1990, evidence has shown that there is noise exposure outside the workplace that is potentially damaging. [19 20] It would be necessary to set the occupational noise exposure level at the average level experienced by those exposed nonoccupationally because recovery of temporary threshold shift (TTS) is not guaranteed.[21 22] It should be considered that nonoccupational noise exposure can aggravate TTS caused by occupational noise exposure rather than treat it. The American Conference of Governmental Industrial Hygienists (ACGIH) TLV® (Threshold Limit Value) for noise are based on the assumption of a nonoccupational 16-hr hearing recovery time at a noise level of less than 75 dBA, which indicates that if a worker for a whole day (24 hr) is restricted to a workplace, the background noise level of the space for relaxation and sleep should be below 70 dBA. [23] Second, there is an assumption that the hearing threshold at the beginning of employment is 0 dB HL, that occupational noise exposure and aging effects are additive, and that noise induced hearing damage stops when noise exposure ceases.[24 25] Recent researches have suggested that these assumptions may not indicate the real development of NIHL. Some studies have shown that ears with previous noise damage may suffer exacerbated age-related hearing loss.[26-28]

Table 1-3. Summary of estimating the excess risk of material hearing impairment (40 years of exposure, 2000 hr per year)

Average exposure level, dBA	0.5-1-2-kHz Definition [a] (% hearing impairment)					1-2-3 kHz Definition [a] (% hearing impairment)			1-2-3-4 kHz Definition [a] (% hearing impairment)	
	ISO 1999 (1971)	NIOSH (1972)	EPA (1973)	ISO 1999 (1990)	NIOSH (1997)	NIOSH (1972)	ISO-1999 (1990)	NIOSH (1997)	ISO-1999 (1990)	NIOSH (1997)
90	21	29	22	3	23	29	14	32	17	25
85	10	15	12	1	10	16	4	14	6	8
80	0	3	5	0	4	3	0	5	1	1
75	-	-	0	-	-	-	-	-	-	-

ISO, International Organization for Standardization; NIOSH National Institute for Occupational Safety and Health; EPA, US Environmental Protection Agency

[a] The definition of material hearing impairment is different from institution to institution. The frequencies are used to determine material impairment, this table was cited from ref 14 (Bruce RD et al., 2011).

Table 1-4. Margin of safeties and exposure limits of noise for preventing NIHL

Source	Exposure duration	Margin of safeties	Exposure limits
Occupational noise	8 hr	80 dBA in ISO, NIOSH 75 dBA in EPA	L_{NIOSH}=85 dBA (ER= 3 dB) L_{OSHA}=L_{MOEL}=90 dBA (ER=5 dB) EU $L_{ex,8h}$=80/85/87 dBA (ER=3 dB)
Nonoccupational noise	16 hr	75 dBA in ACGIH	
Occupational nonoccupational	24 hr	70 dBA in EPA, WHO	$L_{eq,24h}$=70 dBA in EPA, WHO (ER=3 dB)

ER, exchange rate

If these findings are confirmed, the ISO-1999 model may underestimate the NIHL risk and need to be revised. The ISO-1999 standard also offers two reference databases: database A, based on a highly screened non-noise-exposed population excluding otologic disease, and annex B, an alternative database representing a typical otologically unscreened population of an industrialized country, not occupationally exposed to noise. There are some problems to be revised here as well. First, these databases are based on populations of North American and European countries, which may or may not be used for comparison of the risk of other populations. Second, annex B, which is especially important for cross-sectional risk assessment, is quite old, based on the US National Health Examination Survey of 1959–1962. Raw audiometric data of ISO-1999 can be obtained, but performing statistical analyses in cross-sectional studies using this database is difficult.[29-31]

Although ISO-1999 gives a consensus indicator of the relationship between NIHL and noise exposure, it is not a destination but a pathway. The first thing to consider under the risk assessment principle is avoidance of the noise source followed by evaluation of noise exposure. The importance of competent noise exposure assessment is raised here and is why ISO-9612 on noise exposure assessment was recently revised prior to ISO-1999. In fact, the new above-mentioned EU Directive provided impact for this ISO-9612 2009 revision. The need for accurate and effective noise exposure assessment is growing. ISO-9612 represented three exposure assessment methods: full-day measurement, a task-based (TB) method, and a job-based method. In particular, the TB method and job-based method were newly introduced and provide ways to assess the noise exposure from various sectors and occupations. For example, the TB method is useful for assessing each operating conditions observed versus the routine operating conditions. Furthermore, the TB method could check the uncertainty of the measurements between them.[32 33]

In summary, noise and NIHL are common hazards and health problems; thus, related international standards and laws exist. If we can understand the drawbacks of and changes in these standards and laws, we can review the status and outlook of noise exposure and NIHL. The EU provided the foundation for extensive noise-risk assessment. This will render an increasing portion of the

NIHL iceberg visible over time. In view of this, there are many missing and underserved population in Korea.

1.2. Research scope and overview

In this study, assessment of noise exposure among construction workers, firefighters, musicians, office workers, service workers, housewives, and students was conducted. Little research has focused on noise exposure assessment of these occupations, and these groups represent underserved occupations that have been excluded from occupational health services in Korea. In particular, construction workers, firefighters, and musicians tend to accept loud noise as inevitable. On construction sites, management focuses on safety more than health issues such as NIHL. During firefighting and rescue missions, firefighters' serious health risks are ignored. Music is generally perceived as pleasurable, not a risk to health. Office workers, service workers, housewives, and students were not thought to be adversely affected by noise, so they were used as the control group for a cross-sectional study of NIHL. Recent research on the global burden of NIHL suggested that one source of uncertainty is the noise exposure and NIHL of white-collar workers; this control group may in fact develop NIHL to a degree beyond that in the general population. [34]

Adequate risk assessment for preventing NIHL must take into account all noise exposure. In this study, both occupational and nonoccupational noise exposure were measured. Official efforts to evaluate noise exposure assessment have focused traditionally on occupational settings, but environmental noise continues to grow in extent, frequency, and severity as a result of population growth, urbanization, and technological developments. Recent studies have suggested that specific noise levels outside the workplace are potentially damaging. [19 20]

This dissertation consists of 6 chapters. Chapter 1 presents an introduction that reviews research backgrounds and associated objectives of this study. In chapter 2, We evaluated noise exposure level of construction workers, the occupational noise exposure assessment was conducted with 139 construction workers from ten construction trades working at an apartment construction site. The assessment was performed by the Ministry of Employment and Labor (MOEL) method which is same to that of U.S. Occupational Safety and Health Administration (OSHA). In chapter 3, We evaluated the noise exposure levels of underserved occupations including 7 firefighters, 5 Korea traditional music apprentices, 6 office workers, 3 service workers, 9 graduate and undergraduate students, and 9 housewives for 24-hr periods over 7 days. To determine the contribution of each microenvironment (ME) to total noise exposure, participants were asked to attach the noise dosimeters and complete a time–activity diary (TAD) 24 hr a day for 7 days.

In chapter 4, we investigated firefighters' 24 hour full-shift noise-exposure assessments with task based information because firefighters are commonly exposed to short term, intermittent, high-intensity noise, unlike the continuous noise levels found in manufacturing. In chapter 5, whether firefighters are at risk of NIHL remains controversial, comparisons of the hearing thresholds of firefighters with two age-matched Korean general population-based data sets were performed.

1.3. Objectives

The overall objectives of this study were to assess the occupational noise exposure of underserved occupations and their nonoccupational activities that have been excluded from previous researches. Therefore, the specific objectives of this study are listed as follows :

1) To assess the occupational noise exposure levels of construction workers at apartment construction sites, typical construction site in South Korea
2) To evaluate the noise exposure levels of underserved occupations 24 hour a day for 7 days and to determine the contribution of noise exposure from each microenvironment (ME) including occupational and nonoccupational site to total sound exposure

3) To evaluate the firefighters’ noise exposure levels associated with specific tasks and their contributions to total noise exposure by 24-h full-shift noise-exposure assessments with task-based information
4) To evaluate the risk of firefighters’ NIHL in by cross-sectional study : comparisons of hearing thresholds of firefighters with two age-matched population-based data sets

Chapter 2.

Assessment of apartment construction worker noise exposure

This chapter was presented in Korea Industrial Hygiene Association Conference (2011.02.11)

2.1. Introduction

Construction is an occupational area characterized by exposure to high levels of noise and thereby involves a number of proven cases of NIHL in developed countries. According to the NIOSH of the USA, the ratio of construction workers exposed to 85 dBA or greater noise is 15.6-24.0%, depending on their tasks. This translates to approximately 8.43 million people.[16] Furthermore, the longitudinal study conducted recently in Washington with a construction worker cohort over 10 years also stated that construction workers were exposed to an average 87 dBA of noise.[35] It has been scientifically confirmed that this causes a significant increase in the hearing threshold level (HTL) even after compensating for the age effect and nonoccupational noise exposure.[35] A German study also showed that 45.3-62.6% of blue collar workers, depending on different construction trades- subgroups with different professional skills- of the construction industry, suffered from NIHL, with a prevalence rate 1.2-1.75 times higher than that among white collar workers.[36] A cross sectional study conducted in Taiwan on approximately 10,000 workers also showed that construction workers occupied the largest portion of severe NIHL cases (38.6%).[37]

There are no studies on the prevalence of NIHL in Korean construction workers, and the official records of workers' compensation insurance are the only available data. 5 out of approximately 1.7 million construction workers have compensated because of NIHL every year, on average.[38] According to the 2nd Korean Working Condition Survey [2] held in 2010, 56% of construction workers responded that they were being exposed to loud noise to the degree that they needed to speak in a loud voice to colleagues working alongside them in order to communicate during work. This figure was quite large next compared to mining workers (68%). The Occupational Safety and Health Act revised in 2004 obligates the construction industry to perform noise exposure assessments as well as health examinations.[39] However, the implementation rate at actual construction sites is quite low.[3 4 6] In construction sites of Korea, occupational safety control mostly focuses on preventing work related accidents. Noise is not yet recognized as a hazardous factor. The construction workers in Korea are a much more “underserved population” than construction workers in the USA. [40 41]

The noise exposure assessment at the actual construction site is quite difficult from in the manufacturing industry, due to the characteristics of a construction site. There are not many changes in operators and processes in the manufacturing industry, but there are frequent changes in workers and processes in the construction industry. In other words, it is impossible to set up a homogeneous exposure group, which is considered to be basic and essential for any thorough hazard exposure assessment. [23] In the construction industry, many construction trades operate on the same site simultaneously or subsequently, depending on the process, within a limited construction period.

Under those circumstances, the trade mean (TM) method in the assessment of exposure to hazardous factors including noise was applied. Most studies in the past accessed the trade mean in a variety of construction sites.[42] Each construction trade has unique operations, but construction type varied and so did the construction trades that operate together, depending on the site. This means that construction workers' exposure to hazardous factors can vary somewhat even within the same construction trade, depending on the construction type. This study narrowed the subject of study down to apartment construction sites in order to reduce the number of variables. The apartment complex is the typical housing style in Korea and is one of the construction types to involve a great number of construction workers. Apartment construction uses reinforced concrete as the main material and a variety of types of operations including pile driver operator, chipping, and stone working take place in a relatively small working space.

The purpose of this study is to secure the basic data for occupational hygiene control of construction workers by analyzing the noise exposure assessment regarding construction workers at apartment construction sites, typical construction sites in Korea, by construction trade, size of construction company, the total number of workers on the construction site, and the number of workers in each construction trade.

2.2. Materials and methods

Subjects

The measurements taken from 53 apartment construction sites in the northern part of Gyeonggi-do during 2005-2008 were obtained from an institute designated as the Work Environmental Monitoring Institution by the Ministry of Employment and Labor, and has been conducting work environment monitoring. As work environment monitoring can be conducted on the process for a TWA of 80 dBA or higher according to the Occupational Safety and Health Act, the institution's industrial hygienist choose the construction trades that fall under this category through a preliminary survey. 10 construction trades were measured in a total of 53 apartment construction sites, and 139 out of 1,188 construction workers who operated at those sites were measured. Table 2-1 shows the number of samples in each construction trade, construction site, and the number of construction companies. 20 out of 148 pile driver operators and 28 out of 1,199 concrete carpenters were selected and assessed for noise exposure. In other construction trades, 37 out of 82 concrete chippers, 23 out of 79 concrete finishers, and 12 out of 119 masons were selected and assessed. Additionally, 11 out of 166 interior carpenters, 3 out of 9 ironworkers, and 5 out of 62 tile setters, waterproof workers, and facility workers were selected and assessed for noise exposure level (Table 2-1).

Noise exposure measurement

The noise exposure assessment was conducted according to the Work Environment Monitoring and Quality Control as notified by the Ministry of Employment and Labor. The assessment used a noise dosimeter (TES 1355, TES Electrical Electronic Corp. Taiwan) and measurements were taken with Property A. Criteria was 90 dB, the threshold was 80 dB, the exchange rate was 5 dB, and the assessment was conducted over 6 hours.

Table 2-1. Subjects of noise exposure monitoring

Construction trade	Main noise sources	No. of samples	No. of Companies	No. of Construction sites	No of workers
Pile driver operator	Hammer impact on pile, diesel engine	20	6	8	148
Concrete carpenter	Hand hammer, impact of pipe support, prying of crowbar	28	7	10	523
Concrete chipper	Jackhammer,	37	17	14	82
Concrete finisher	Grinding	23	12	10	79
Masonry worker	Masonry saw	10	6	6	119
Interior carpenter	Nail gun, hammer	13	6	6	166
Ironworker	Cutter	3	2	2	9
Other groups [a]	Hammer etc.	5	3	3	62
Total		139			1188

[a] Other groups : Tile setter, waterproof worker and facility worker

Statistical analysis

Because the noise levels measured were normally distributed on the whole and for each construction trade, the mean value and the standard deviation were presented as the representative values. For the difference in noise exposure between construction trade, size of the construction company, and the number of workers on each construction site, the ANOVA was conducted. SAS 9.3 (SAS Institute, US) was used as the statistical software.

2.3. Results

Noise exposure by construction trade

Table 2-2 represents the results of noise exposure for 139 apartment construction workers. 139 construction workers were exposed to a mean of 87.8 dBA, minimum 78.3 dBA, and maximum 99.3 dBA of noise, and among 139 cases, the noise exposure exceeded 85 dBA in 101 cases (72.7%) and even 90 dBA, in 38 cases (27.3%). By construction trade, pile driver operators were exposed to a mean of 85.6 dBA and 17 out of 20 cases (85.0%) exceeded 85 dBA. None exceeded 90 dBA. Concrete carpenters were exposed to a mean of 84.0 dBA, and 12 out of 28 (42.9%) were exposed to 85 dBA or greater noise levels. None exceeded 90 dBA. Concrete chippers were exposed to a mean of 93.2 dBA, and 37 out of 37 (100%) were exposed to 85 dBA or greater noise levels, and in 19 cases (89.1%), the noise exposure exceeded 90 dBA.

Table 2-2. Noise exposure level for construction workers by construction trade

Construction trade	N	Mean (SD) dBA	Range dBA	N (%) >85 dBA	N (%) >90 dBA
Pile driver operator	20	85.6 (1.7)	80.3~87.4	17 (85.0)	0 (0.0)
Concrete carpenter	28	84.9 (2.4)	79.1~89.2	12 (42.9)	0 (0.0)
Concrete chipper	37	93.2 (2.6)	87.7~99.3	37 (100.0)	19 (89.1)
Concrete finisher	23	88.3 (2.7)	83.2~94.1	20 (87.0)	4 (17.3)
Masonry worker	10	87.7 (1.9)	85.9~90.8	10 (100.0)	1 (10.0)
Interior carpenter	13	83.5 (2.1)	81.0~89.2	1 (7.7)	0 (0.0)
Ironworker	3	88.4 (0.7)	87.8~89.2	3 (100.0)	0 (0.0)
Other groups	5	81.4 (2.2)	78.3~83.6	0 (0.0)	0 (0.0)
Total	139	87.8 (4.3)	78.3~99.3	101 (72.7)	38 (27.3)

N, number (of construction workers who participated in noise sampling); SD, standard deviation

Concrete finishers were exposed to a mean of 88.3 dBA, and 20 out of 23 (87.0%) were exposed to 85 dBA or greater noise levels. In 4 cases (17.3%), the noise exposure exceeded 90 dBA. Masons were exposed to a mean of 87.7 dBA, and 10 out of 10 (100.0%) were exposed to 85 dBA or greater noise levels. In 1 case (10.0%), the noise exposure exceeded 90 dBA. Interior carpenters were exposed to a mean of 83.5 dBA, and 1 out of 13 (7.7%) was exposed to 85 dBA or greater noise levels. None exceeded 90 dBA. Ironworkers were exposed to a mean of 88.4 dBA, and in 3 out of 3 cases (100%), the exposure level was 85 dBA or greater. However, none exceeded 90 dBA. Tile setters, facility, and waterproof workers were exposed to a mean of 87.8 dBA, and all 5 of them were not exposed to noise at or above 85 dBA (Table 2-2).

Comparison of noise levels between noise factors

Table 2-3 shows the noise exposure level by company size, total workers of construction site and the number of workers per work unit sampled. We divided the size of construction companies into three groups according to their construction capacity ranking as of 2007 : large corporations (ranked top 20), companies of middle standing (ranked from 21 to 50), and small enterprises (ranked lower than 50). The numbers were 87.7 dBA for large corporations, 87.4 dBA for companies of middle standing, and 88.7 dBA for small enterprises, and there was no significant difference between the groups (p=0.35). For each place of business, the number of workers was divided into 100 or less, 101-500, and 501 or more. The noise exposure levels were compared. The average noise exposure level was 88.0, 87.4, and 88.4 dBA, respectively, and there was no significant difference between groups (p=0.61). The number of workers per work unit of each construction trade was divided into 5 or less, 6-10, and 11 or more, and the noise exposure level was compared.

The noise exposure level for the 5 or less group was 90.2 dBA, and that for the 6-10 group was 86.9 dBA. That for the 11 or more group was 84.7 dBA, and there was a significant difference between groups based on the noise exposure level ($p<0.001$).

Table 2-4 demonstrates the noise exposure level by construction trade. According to the ANOVA Bonferroni analysis, there is a significant difference in noise exposure level between construction trade groups. Concrete chippers showed the highest noise exposure levels among all construction trade groups, 7.6 dBA higher than that for pile driver operators ($p<0.001$), 8.3 dBA higher than for concrete carpenters ($p<0.001$), and 4.9 dBA higher than for concrete finishers ($p<0.001$). Furthermore, it was 6.1 dBA higher than for masonry workers ($p<0.001$), 9.8 dBA higher than for interior carpenters ($p<0.001$), 4.8 dBA higher than for ironworkers ($p=0.03$), and 10.7 dBA higher than for other groups ($p<0.001$).

The noise exposure level of ironworkers was 5.0 dBA higher than for interior carpenters ($p=0.044$) and 5.9 dBA higher than for other groups ($p =0.018$). The noise exposure level of concrete finishers was 2.7 dBA higher than for pile driver operators ($p=0.011$), 3.4 dBA higher than for concrete carpenters ($p<0.001$). It was 4.9 dBA higher than for interior carpenters ($p<0.001$), and 5.8 dBA higher than for other groups ($p<0.001$). The noise exposure level of masonry workers was 3.7 dBA higher than for interior carpenters and 4.6 dBA higher than for other groups ($p=0.005$).

Table 2-3. Noise exposure level by company size, total workers of construction site and the number of workers per work unit

Variables		N	Mean	SD	95% CI	F	*p*
Company size	Large	46	87.7	4.5	86.4~89.1	1.04	0.35
	Middle	63	87.4	4.0	86.4~88.4		
	Small	30	88.7	4.5	87.1~90.4		
Total workers	≤100	59	88.0	4.4	86.9~89.2	0.50	0.61
	101~499	64	87.4	4.3	86.3~88.5		
	≥500	16	88.4	4.3	86.1~90.7		
No. of workers per work unit	≤5	69	90.2	3.8	89.3~91.1	34.78	<0.001
	6~10	22	86.9	4.2	85.0~88.7		
	≥11	48	84.7	2.7	83.9~85.5		

N, number of construction workers who participated in noise sampling; SD, standard deviation

Table 2-4. The noise exposure level by construction trade (ANOVA Bonferroni analysis)

Job (A)	Job (B)	Difference (A-B)	95% CI	*p*
Concrete chipper	Pile driver operator	7.6	5.4~9.7	<0.001
	Concrete carpenter	8.3	6.4~10.3	<0.001
	Concrete finisher	4.9	2.9~6.9	<0.001
	Masonry worker	6.1	3.5~8.6	<0.001
	Interior carpenter	9.8	7.2~12.4	<0.001
	Ironworker	4.8	0.2~9.4	0.030
	Other groups	10.7	7.3~14.0	<0.001
Ironworker	Pile driver operator	2.8	-2.0~7.5	1.000
	Concrete carpenter	3.6	-1.1~8.2	0.444
	Concrete finisher	0.1	-4.6~4.8	1.000
	Masonry worker	1.3	-3.6~6.2	1.000
	Interior carpenter	5.0	0.1~10.0	0.044
	Other groups	5.9	0.5~11.3	0.018
Concrete finisher	Pile driver operator	2.7	0.3~5.0	0.011
	Concrete carpenter	3.4	1.3~5.6	<0.001
	Masonry worker	1.2	-1.5~3.9	1.000
	Interior carpenter	4.9	2.1~7.7	<0.001
	Other groups	5.8	2.3~9.3	<0.001
Masonry worker	Pile driver operator	1.5	-1.3~4.3	1.000
	Concrete carpenter	2.3	-0.4~4.9	0.193
	Interior carpenter	3.7	0.6~6.9	0.007
	Other groups	4.6	0.8~8.4	0.005
Pile driver operator	Concrete carpenter	0.8	-1.5~3.0	1.000
	Interior carpenter	2.3	-0.6~5.1	0.359
	Other groups	3.1	-0.4~6.7	0.156
Concrete carpenter	Interior carpenter	1.5	-1.2~4.2	1.000
	Other groups	2.4	-1.1~5.8	0.848
Interior carpenter	Other groups	0.9	-3.0~4.7	1.000

2.4. Discussion

Environmental noise is being measured at construction sites in Korea considering possible civil complaints from local residents, but occupational noise exposure assessment has been rather neglected. There have been few studies to measure the workers' noise exposure at apartment construction sites, the typical construction site in Korea. The noise exposure of 139 construction workers in 10 construction trades at apartment construction sites were assessed, and the mean noise exposure was 87.8±4.3 dBA, at least 27% in excess of the KOEL. As the exposure to 85 dBA or higher noise involves a substantial risk of NIHL, 71.9 % or more construction workers assessed are at risk. The number of workers at risk can be increased, when another assessment method is applied. Neitzel et al. assessed the noise exposure of a Washington construction worker cohort using the NIOSH method and OSHA method, the method applied in this study. Their measurement by the NIOSH method was approximately 7.7 dBA higher, and the subjects of this study would exceed the exposure standard if this criteria was applied (Figure 2-1). [43]

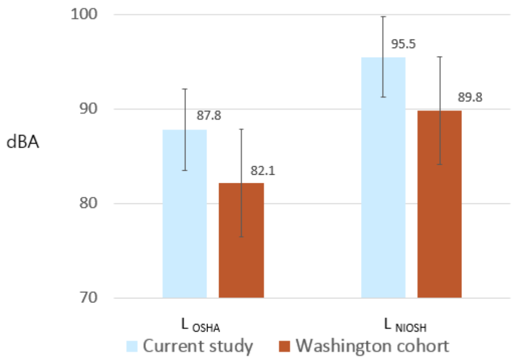

Figure 2-1. Comparison of mean noise exposure level of construction workers between current study and Washington cohort

The Washington construction worker cohort assessed noise exposure of 730 workers in 9 construction trades, and the mean level was L_{OSHA}=82.1±5.7 dBA, which is substantially lower than the results of this study. For the difference in the number of construction trades and samples in both studies, it is necessary to compare the data by construction trade, and the exposure level of comparable construction trades such as carpenters, masonry workers, and ironworkers in this study was generally 2-5 dBA higher. This does not fully explain the difference of 5 dB or greater in the mean value, and the reason is estimated to be the application of a worst-case investigation method in this study, as it was a legal measurement. In other words, electricians with relatively low exposure levels accounted for the largest portion of the subjects in the Washington cohort, while concrete chippers, represented the largest share of subjects of this study. 44

In the Washington cohort, the exposure levels of ironworkers and operating engineers were the highest, and those of ironworkers and pile driver operators were also relatively high in this study. However, in the Washington cohort, the difference in exposure level by construction trade was not significant, while the difference appeared to be significant in this study. This can be attributed to the fact that the subjects of this study included a large number of concrete chippers and concrete finishers, which are construction trades not included in the Washington cohort. Chipping and grinding are usually processes of correcting defects during the concrete work in construction sites, and they can be minimized at well-designed construction sites. The reason construction sites in Korea involve a lot of these processes can be estimated that the design and construction process is not organically managed, compared with the USA. The fact that the noise exposure level is significantly high in construction trades with small numbers of workers is also related with chipping and grinding, as these operations are conducted with the minimum number of workers mainly when there are concrete defects.

The noise exposure level of concrete carpenters and interior carpenters is relatively low, however, which is quite significant in the management aspect for these two construction trades involving a large number of workers. In the study of the Washington cohort, electricians were expected to be exposed to very low noise levels, but the actual noise exposure level was only 2-3 dBA lower than those exposed in the construction trades exposed to loud noise, such as ironworkers. The reason was that they were exposed to noise in the form of background noise, while operating in the proximity of the construction trades that were exposed to the loudest noises. [45]

In the Washington cohort, approximately 40% of workers exposed to 85 dBA or higher noise levels used earplugs.[46] In this study, no subjects used earplugs. This is because occupational safety and health at construction sites in Korea mostly concentrates on preventing accidents and disasters, and does not consider even the minimum knowledge about occupational health issues including noise. The Occupational Safety and Health Act requires workplaces of a certain scale to appoint a health manager. However, this excludes construction sites.[7] In other words, the level of industrial health management is the same for both large and small companies, and this is supported by the fact that the noise exposure level did not differ according to the business scale. The authorities need to more intensively enforce related laws and regulations at construction sites to protect the hearing of construction workers in the future. At the same time, it is necessary to assess noise exposure levels of a greater number of construction trades at many different construction sites, along with audiometric testing.

In addition, the fact that there were significant differences between construction trades indicate that construction trade is useful exposure metrics and TM method would be appropriate to assess noise exposure in construction site.

There are a few limitations in this study. First, apartments are constructed by large corporations in most cases in Korea, so this study cannot be considered as a fair representation of noise exposure on all construction sites nor for construction sites of other types of buildings. Second, the measurements taken in the study are worst-case measurements and are not considered as the average noise exposure levels at most apartment construction sites.

2.5. Conclusions

In conclusion, the results indicated that almost construction workers in this study are at risk of noise induced hearing loss (NIHL) and construction trade is useful exposure metrics in apartment construction site. Authorities should more intensively enforce related laws and regulations including exposure assessment and hearing examinations for the protection of the hearing of construction workers and also continuously promote related studies.

Chapter 3.

Assessment of noise measurements made with continuous monitoring over time (24 hours/7 days) among underserved occupations

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3.1. Introduction

According to the World Health Organization (WHO), hearing loss is one of the top 10 most serious health problems worldwide, and noise induced hearing loss (NIHL) is the leading occupational disease.[47 48] Official efforts to evaluate noise exposure assessment have traditionally focused on occupational settings, but environmental noise continues to grow in extent, frequency, and severity as a result of population growth, urbanization, and technological developments. Recent studies have suggested that specific noise levels outside the workplace are potentially damaging.[19 49] Noise exposure assessment, which includes both occupational and nonoccupational exposure, has not been extensively studied. Working hours are part of an individual's 24-hr day, and both occupational and nonoccupational noise exposure should be considered to evaluate the daily and lifetime dose. The U.S. Environmental Protection Agency (EPA) estimated that to protect virtually the entire population from any significant noise induced permanent threshold shift, noise exposures should be limited to an $L_{eq\ 24hr}$ of 70 dB. [15] Also, the WHO recommended a daily average noise exposure equivalent to $L_{eq\ 24hr}$ of 70 dBA for hearing safety. [18] The American Conference of Governmental Industrial Hygienists (ACGIH) exposure criteria are based on the assumption of a 16-hr hearing recovery time (nonworking time) at a noise level of less than 75 dBA. This indicates that when a worker (for more than 24 hr) is restricted to a space that serves as both a workplace and a place to relax and sleep, the background noise level of the space for relaxation and sleep should be below 70 dBA. [50]

Few studies have evaluated daily personal noise exposure by measuring both occupational and nonoccupational settings, and few data are available describing weekly noise exposure. However, Schori and McGatha (1978) followed subjects for 7 days, and included five different groups of 50 participants. In a 1994 study by Berger and Kieper (1994), the exposure results of 20 individuals (each measured over 7 days for 24 hr) were reported. By utilizing a 7-day, 24-hour approach, work, sleep, hobbies, home tasks, and social activities were included. [51] These studies advanced our understanding of nonoccupational and occupational exposure. However, explanations on the source and cause of the exposures were not provided in detail, and data were limited. Neitzel et al. (2004a, b) conducted a noise measurement of 31 construction workers for 4 consecutive days (including 2 nonworking days) with free-field activity logs. Diaz and Pedrero (2006) measured $L_{Aeq\ week}$, $L_{Aeq\ 24hr}$, and sound exposure(Pa^2hr) of 32 individuals based on a series of self-reported activities such as occupational, domestic, leisure, shopping, sleep, and transportation in Madrid, Spain. Measuring personal noise exposure using time–activity logs generated detailed spatiotemporal information on noise activities. These studies identified contributions to total noise exposure from occupational and nonoccupational sources, confirming a high risk from nonoccupational noise exposure. Exploring other sources of noise (in addition to occupation) using long-term personal monitoring may continue to expand our understanding of overall noise exposure in the 21st century. Furthermore, Asian culture and lifestyle differ from Western countries; thus, the Asian noise exposure profile might differ from previous studies. Environmental sustainability and environmental health have been overlooked in Asian countries for several decades as a result of rapid economic development. Recently, the government, researchers, and nongovernmental organizations have examined studies from other developed countries and found that noise exposure is a major issue. For example, the Korean government recently recognized the importance of noise exposure to general citizens, but very few data are available.[52] The purposes of this study were to evaluate the noise exposure levels of several job categories 24 hr a day for 7 days and to determine the contribution of each microenvironment (ME) to total sound exposure.

3.2. Materials and methods

Participants

The 47 participants included 28 men and 19 women, ranging in age from 20 to 50 years, who were classified into eight occupational groups. The eight groups included nine housewives, nine graduate and undergraduate students, six office workers, four industrial hygienists, three service workers, four heavy equipment operators, seven firefighters, and five Korean traditional music apprentices in the Seoul National Capital Area. Because the sampling of this study was very intensive and intrusive into private life, only motivated participants who accurately completed their time–activity diary (TAD) were included. Eighteen of 47 participants, including housewives, office workers (3 accounting clerks, 3 administrative assistants), and service workers (2 retail workers, 1 bakery clerk), were enrolled in the Korea National Open University. These participants majored in environmental health and were employed during the sampling period. The other 29 subjects were selected through acquaintances in the universities, the labor union, and local fire departments. Nine students and five Korean traditional music apprentices (4 percussionists, 1 string player) were recruited from three universities. Also, four heavy equipment operators (2 tower crane operators, 2 backhoe operators) and seven firefighters (2 suppressors, 2 rescuers, 2 drivers, 1 investigator) were recruited from the labor union and two local fire departments, respectively (Table 3-1). Three of four industrial hygienists were employed by different industrial hygiene companies, while the other worked as a labor inspector.

During the sampling period, participants were required to carry a noise dosimeter and to complete a TAD. The sampling period ranged from September 2010 to September 2011. Informed consent was obtained from participants and the study protocol was approved by the institutional review board (IRB) of the Graduate School of Public Health in Seoul National University.

Noise measurement

Participants wore data-logging dosimeters (model 706 RC; Larson Davis, Provo, UT, USA) for 1 week (Table 3-1). The microphone was placed midway between the person's neck and shoulder (near the ear) in an upright position and clipped on to the strap of the small bag that contained the data logger, which was given to participants for convenience and to exclude the participant's speaking noise. The dosimeter had a dynamic range of 103 dB (40–143 dB), with a noise floor of 40 dBA. Data used in the current analysis were 1-min sound pressure levels (1-min L_{eq}) in decibels (dB) recorded using "A" frequency weighting, slow meter response, and a 3-dB exchange rate with no minimum threshold. The recorded data were downloaded either every day, or two or three times a week. Dosimeters were calibrated before they were worn and checked again when the recorded data were downloaded and when the dosimeter was returned. Some participants recorded their activity on a cellular phone and copied it onto the TAD. Text messages were sent frequently as a reminder to complete the TAD. The diary and recorded data were checked every day, or two or three times during the sampling period by a researcher. Approximately 1,380 measurements, taken every minute for 24 hr a day, were recorded by real-time monitoring each day during the sampling period. The measurement period was 7 days, but slight changes were applied to the sampling duration according to a participant's life pattern, instrument calibration, and data download. The firefighters were sampled for 6 days to measure three duty cycles because they worked 24-hr shifts, 7 times every 2 weeks. Two heavy equipment operators who worked 6 consecutive days were sampled for 8 days to measure their 2 days off-duty followed by 6 consecutive days of work. Korean traditional music apprentices and two participants in office workers were sampled for 6 days because of their distance and accessibility.

The subjects were given practical instructions to keep the dosimeter at hand at all times and beside their bed when they slept, and with the microphone close to the ear, unless a specific activity made that impossible. Extra batteries were available in the dosimeter since the dosimeter could run for about 100 hr of continuous use on two AA alkaline cells. They were encouraged to call the researcher for assistance, if necessary. Participants completed the TAD, which included detailed information on the activity and ME. Five MEs were categorized according to the TAD; home, workplace/school, other indoor (e.g., restaurant, shopping mall, karaoke), outdoor (exercise outdoors, stroll, hiking, outdoor event), and transportation (bus, subway, automobile, taxi, scooter). Previous studies (Berger and Kieper 1994; Diaz and Pedrero 2006; Schori 1978) sampled noise over a period of 1 week and used the weekly energy average (logarithmic means) as a representative value of $L_{eq\ 24hr}$ for an individual, which was called $L_{eq(24)}$s, Leq(week), or $L_{Aeq\ week}$. These expressions can be confused with 1 day $L_{eq\ 24hr,}$ or an arithmetic mean of 7 days. In this study, to avoid confusion, we represented this noise descriptor as $L_{eq\ 24hr,w}$. L_{eq}

$_{24hr,d}$ is comparable to $L_{eq\ 24hr}$ for 1 day, which is similar to the EU in an occupational setting. EU members have used the weekly noise exposure level ($L_{ep,w}$) in place of the daily noise exposure level ($L_{ep,d}$) to assess the levels of noise to which workers are exposed. This weekly exposure level is applicable when noise exposure varies markedly from day to day, and can be applied to occupational exposure limits and action values. [1] $L_{eq\ 24hr,w}$ and the mean of $L_{eq\ 24hr,d}$ for 1 week were calculated and compared.

Data analysis

Data were downloaded to the Blaze software program (Blaze; Larson Davis, Provo, Utah) and exported to Excel 2007 (Microsoft, Redmond, WA) to calculate the noise descriptor. Each subject's $L_{eq\ 24hr,w}$ levels were calculated by identifying subject-specific sequences of consecutive 1-min intervals for approximately 1 week using Equation (1). [49]

$$L_{eq\,24h,\,w_i} = 10\log_{10}\frac{1}{n_i}\sum_{k=1} 10^{L_{eq\ ik}/10}, \qquad (1)$$

where n_i is the duration of the measured minute over 7 days (~ 9,294 min) for an $L_{eq\ 24hr,w\ i}$ for participant *I*, and $L_{eq\ ik}$ is the noise level for participant *i* during a 1-min noise interval *k*. Using Equation (1) for each day (mean 1,380 min), seven $L_{eq\ 24hr,d}$ values per participant were generated. The arithmetic mean of

$L_{eq\ 24hr,d}$ during each of the 5 weekdays and the 2 weekend days of each group were also calculated.

To calculate weekly personal noise exposure levels in the ME ($L_{eq\ ME,w}$), log data of the TAD and their corresponding 1-min L_{eq} level data were aggregated by participant, and ME-specific $L_{eq\ ME\ w}$ values for each participant were calculated using Equation (2):

$$L_{eq\,ME\,w_{ij}} = 10\log_{10}\frac{1}{n_{ij}}\sum_{k=1} 10^{L_{eq_{ijk}}/10}, \qquad (2)$$

where n_{ij} is the number of minutes that a participant i is in ME j and $L_{eq\ ijk}$ is the SPL (Sound pressure level) recorded for participant i and ME j during a 1-min noise interval k. Occupational and nonoccupational noise L_{eq} for a week ($L_{eq\ O,w}$, $L_{eq\ NO,w}$) were calculated using the same method. $L_{eq\ O,w}$ is the same as $L_{eq\ ME\ w}$ in workplace/school, and $L_{eq\ NO,w}$ was calculated by energy averaging 1-min L_{eq}s in the other four MEs based on Equation (2).

The contribution of total noise exposure levels in each ME was evaluated by Pa^2hr, an energy term which was introduced by ISO 1999.[13 53 54] Acoustic power was proportional to sound pressure squared, and power was defined as energy transfer per unit time.[55 56] Sound exposure (SE), in Pa^2hr, occurring during a time T, in hours, can be determined from Equation (3):

$$SE = (p_{ref}^2 T)\times 10^{\frac{L_{eq},T}{10}}\ Pa^2hr, \quad p_{ref} = 20\mu Pa \qquad (3)$$

Statistical analysis

Descriptive statistics were used to generate the results of the general participant characteristics (time spent in each ME) and noise exposure levels. All data were tested for normality. Arithmetic means and standard deviations were calculated to describe central tendency and variation in each occupational group because the percentages of time spent and the noise exposure levels were normally distributed according to the Shapiro-Wilk test. The same statistics were used to describe overall mean noise exposure levels, although it was right-skewed because of the Korean traditional music apprentice’s high noise exposure levels. ANOVA and Tukey post hoc comparisons were performed to compare time-spent percentages in each ME and noise exposure levels among occupational groups with a significance level of 0.05. A paired *t*-test was performed to evaluate the differences between averages of each participant. SPSS 19.0 software (SPSS Inc., Chicago, IL) was used for statistical analysis.

3.3. Results

Time–activity diary

Time–activity data of 47 participants over eight occupational groups during 7 days are presented in Table 3-1. In total, 436,818 min (95.4%) out of 457,920 min for 47 participants (8 days for 2 persons, 7 days for 34 persons, 6 days for 9 persons, and 5 days for 2 persons) during the survey was recorded. The percentage of time spent in the MEs was calculated based on the 24-hr/7-day diaries. The largest overall percentage of time was spent at home (56.1%), while 24.2% was spent in the workplace/school, 8.7% in other indoor environments, 4.9% outdoors, and 6.2% in transportation. The percentages of time spent indoors (89.1%) including home, workplace/school, and other indoor sites differed among occupational groups ($p < 0.05$), but no significant differences were observed between the time spent outdoors or in transportation among job categories ($p = 0.35$, $p = 0.55$, respectively). The differences in time spent indoors (home, workplace/school, other outdoor) among occupational groups were mainly due to the lifestyle patterns of housewives and firefighters. Firefighters spent the most time at their workplace (49.9%) because of their alternating 24-hour shift schedules and stayed home 36.1% of the time. As expected, housewives spent the most time at home (75.3%), followed by graduate and undergraduate students (58.1%), and service workers (58.1%).

All activities at home were indoors because all participants lived in apartments or detached houses with no yard. The activities at the workplace/school were mainly indoors, excluding firefighters and industrial hygienists, who spent some time outdoors related to their work (dispatch or visiting other companies for consulting). The time spent in other indoor environments was 13.2% for heavy equipment operators and 12.4% for housewives. Heavy equipment operators often went to the union office after work for dinner. After dinner, one heavy equipment operator attended a karaoke event during a survey, which is a common feature of working life in South Korea. Housewives spent time in various indoor MEs such as shopping malls, restaurants, churches, hospitals, libraries, and theaters.

With regard to the transportation ME, most participants used subways and buses. Walking, bicycling, exercising, and attending events outdoors were categorized as outdoor MEs.

Figure 3-1 presents an example of 24-hr real-time noise exposure of an office worker. During time spent at home at night, exposure levels were low (~ 50 dBA), but it increased rapidly to 72 dBA in the morning while the TV, hair dryer, cooker, and oven were used. Exposure during outdoor walking and transportation increased noise levels both during the morning and night (07:30–08:00, 21:45–22:20). During work in the office, exposure was relatively low (58–60 dBA), but typically higher than at home. Also, noise exposure levels after work increased because the participant had dinner and alcoholic beverages with coworkers in a noisy restaurant.

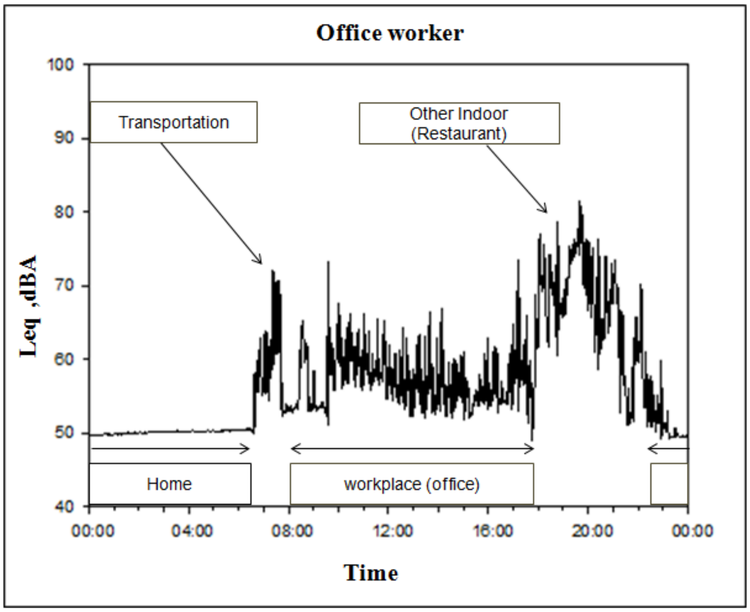

Figure 3-1. Example of a participant's noise levels by time and location during 1 day.

Table. 3-1. Summary of participants and time spent (monitoring time) in each microenvironment (ME)

Occupation	No. of participants			Age (yr)	No. of 1-min noise levels	Average time spent (monitoring time) in minutes of each ME per participant during 1 week, shown as the mean ± SD (%)					
	Total	M	F			Home	Workplace/school	Other indoor	Outdoor	Transportation	Total
Housewives	9	0	9	39–48	86,457	7,238 ± 1,335 (75.3)	122 ± 218[a] (1.1)	1,181 ± 625 (12.4)	518 ± 273 (5.4)	562 ± 245 (5.9)	9,606 ± 501 (100)
Graduate and undergraduate students	9	7	2	20–26	85,028	5,424 ± 847 (58.1)	2,104 ± 1,056 (21.8)	860 ± 474 (9.0)	532 ± 442 (5.6)	528 ± 383 (5.4)	9,448 ± 1,014 (100)
Office workers	6	4	2	29–45	53,565	3,875 ± 1,066 (43.0)	3,533 ± 946 (39.7)	516 ± 194 (5.7)	379 ± 183 (4.2)	624 ± 358 (7.4)	8,928 ± 1,336 (100)
Industrial hygienists	4	3	1	27–37	39,556	5,130 ± 1,072 (52.0)	2,989 ± 1,439 (30.1)	774 ± 483 (7.8)	151 ± 139 (1.5)	846 ± 247 (8.6)	9,889 ± 139 (100)
Service workers	3	1	2	24–47	29,251	5,647 ± 1,105 (58.1)	2,225 ± 482 (22.8)	945 ± 621 (9.6)	351 ± 19 (2.4)	700 ± 421 (7.1)	9,755 ± 324 (100)
Heavy equipment operators	4	3	1	34–50	42,040	5,256 ± 1,459 (49.7)	2,503 ± 1,323 (23.4)	1,370 ± 448 (13.2)	616 ± 367 (6.3)	765 ± 409 (7.4)	10,510 ± 1,847 (100)
Firefighters	7	6	1	28–50	58,973	3,057 ± 652 (36.1)	4,181 ± 387 (49.9)	313 ± 259 (3.7)	561 ± 442 (6.6)	313 ± 139 (3.7)	8,425 ± 539 (100)
Korean traditional music apprentices	5	4	1	23	41,948	5,763 ± 1,449 (68.8)	956 ± 174 (11.9)	717 ± 569 (8.6)	395 ± 307 (4.5)	558 ± 630 (6.5)	8,390 ± 1,811 (100)
Total	**47**	**28**	**19**	23–50	436,818	5,232 ± 1,691 (56.1)	2,256 ± 1,563 (24.2)	822 ± 547 (8.7)	465 ± 335 (4.9)	576 ± 362 (6.2)	9,294 ± 1,177 (100)

M, male, F, female; SD, standard deviation

[a] Some housewives went to the open university to participate in their study group, where the dosimeter was delivered.

Noise exposure level

The noise exposure level for 436,818 min from 47 participants expressed as $L_{eq\ 24hr,w}$, $L_{eq\ 24hr,d}$, and $L_{eq\ ME,w}$ are summarized in Table 3-2 so that the 47 $L_{eq\ 24hr,w}$ levels, 318 $L_{eq\ 24hr,d}$ levels, and 235 $L_{eq\ ME,w}$ levels are presented as an arithmetic mean and standard deviation.

Weekly and daily noise exposure levels: $L_{eq\ 24hr,w}$, $L_{eq\ 24hr,d}$.

The $L_{eq24hr,w}$ range varied widely from 64 to 96 dBA, with a mean ± standard deviation of 74 ± 7 dBA. The Korean traditional music apprentices recorded the highest mean level of weekly personal noise exposure (89 dBA, $p < 0.001$), while other groups did not significantly differ. Even though the noise exposure levels of the remaining groups were categorized into two levels (the 75–77 dBA group consisted of heavy equipment operators, firefighters, service workers, and office workers, while the 71 dBA level group consisted of industrial hygienists, graduate and undergraduate students, and housewives), characterizing the elements separating these two groups and making the exposure levels similar were difficult. For example, office workers were exposed to similar noise levels as students in offices (68 dBA in an office room vs. 69 dBA in a classroom), but they were exposed to higher noise levels in other MEs (home, other indoor, outdoor, and transportation).

Of the 47 participants, 38 (80.9%) were exposed to noise levels greater than 70 dBA, which is the exposure limit recommended by the WHO and EPA. The $L_{eq\ 24hr,w}$ of 15 participants (62.5%) including housewives, graduate and undergraduate students, and office workers exceeded 70 dBA. All industrial hygienists, service workers, heavy equipment operators, firefighters, and Korean traditional music apprentices were exposed to $L_{eq\ 24hr,w}$ levels above 70 dBA. The mean $L_{eq\ 24hr,w}$ value in Korean traditional music apprentices was 89 dBA, and all percussionists were exposed to over 90 dBA with other one-string players being exposed to 89 dBA.

Weekly personal exposure levels in each ME (235 $L_{eq\ ME,w}$ s) from 47 participants were calculated: the mean of each ME by occupational group is shown in Table 3-2. The highest total average $L_{eq\ ME,w}$ was measured in other indoor (78 dBA) and outdoor (78 dBA) environments, followed by transportation (76 dBA), workplace/school (75 dBA), and home (63 dBA). The results of the paired *t*-test to compare each group indicated significantly lower $L_{eq\ ME,w}$ at home than in any other ME ($p < 0.001$), but did not show significant differences among other MEs.

Korean traditional music apprentices were exposed to high noise levels indoors (home, school, and other indoor) compared to other job groups because they practice their traditional percussion and string instruments indoors. In other indoor and outdoor environments, office workers and heavy equipment operators were exposed to noise levels over 80 dBA. At the 95% confidence level, $L_{eq\ ME,w}$ values (excluding the workplace/school) were not significantly different among occupational groups.

The $L_{eq\ 24hr,d}$ with a mean of 71 dBA varied widely among occupational groups, ranging from 46 dBA for an office worker to 103 dBA for a traditional music apprentice (percussionist). A significant difference was observed among groups as determined by one-way ANOVA ($p < 0.001$). A Tukey post hoc test revealed that all groups were categorized into two subsets. The higher exposure group ($p = 0.06$) included Korean traditional music apprentices (80 dBA), heavy equipment operators (75 dBA), firefighters (75 dBA), and service workers (75 dBA), while the lower exposure group ($p = 0.910$) included office workers (69 dBA), housewives (69 dBA), industrial hygienists (68 dBA), and graduate and undergraduate students (67 dBA). The highest daily noise exposure level ($L_{eq\ 24hr,d}$) in the lower exposure group was 90 dBA for an office worker who attended a sports game. The next highest was experienced by an office worker ($L_{eq\ 24hr,d}$ = 87 dBA) who drove her car to go for a hike with loud music on Saturday, followed by a housewife ($L_{eq\ 24hr,d}$ = 87 dBA) on a day when she was exposed to loud music in a health club for 1.8 hr.

Table 3-2. Weekly and daily noise exposure levels ($L_{eq\ 24hr,w}$, $L_{eq\ ME,\ w}$, $L_{eq\ 24hr,d}$)

Occupation [a]	No. [b] of $L_{eq\ 24hr,w}$		Mean of $L_{eq\ 24hr,w}$ and $L_{eq\ ME,w}$ for each microenvironment (ME) during 1 week (SD), dBA						No. of $L_{eq\ 24hr,d}$		Mean[c] of $L_{eq\ 24hr,d}$, dBA		
	Total	> 70 dBA	Total	Home	Work-place /School	Other indoor	Outdoor	Transpor-tation	Total	> 70 dBA	Total	Week	Weekend
Housewives	9	6	71 ± 4	65 ± 3	73 ± 3	75 ± 5	76 ± 6	74 ± 4	63	24	69 ± 6	69 ± 6	68 ± 6
Graduate and under-graduate students	9	4	71 ± 5	59 ± 4	69 ± 4	76 ± 4	77 ± 7	75 ± 5	62	17	67 ± 8	68 ± 5	64 ± 11
Office workers	6	5	75 ± 7	64 ± 8	68 ± 7	81 ± 6	82 ± 11	79 ± 5	41	24	69 ±10	69 ± 9	69 ± 11
Industrial hygienists	4	4	71 ± 1	63 ± 4	64 ± 7	77 ± 7	72 ± 5	76 ± 3	28	13	68 ± 6	70 ± 6	65 ± 5
Service workers	3	3	76 ± 5	66 ± 9	79 ± 2	77 ± 8	79 ± 1	77 ± 4	21	15	75 ± 6	74 ± 6	76 ± 7
Heavy equipment operators	4	4	77 ± 4	64 ± 6	77 ± 3	80 ± 2	83 ± 7	78 ± 4	30	28	75 ± 7	75 ± 5	75 ±10
Firefighters	7	7	76 ± 4	62 ± 5	77 ± 4	74 ± 6	79 ± 5	76 ± 2	42	34	75 ± 5	74 ± 5	76 ± 6
Korean traditional music apprentices	5	5	89 ± 7	67 ± 5	96 ± 10	86 ± 11	75 ± 1	77 ± 6	31	22	80 ±13	82 ±14	77 ± 10
Total	47	38	75 ± 7 74 (64–96)	63 ± 5 64 (52–75)	75 ±10 75 (55–106)	78 ± 7 76 (64–101)	78 ± 7 76 (64–101)	76 ± 4 76 (66–94)	318	177	71 ± 9 71 (46–103)	72 ± 8 71 (46–103)	70 ± 10 71 (48–94)

SD, standard deviation; L_{eq}, Equivalent continuous noise level; dBA, A-weighted decibel ; $L_{eq\ 24hr,w}$, L_{eq} for a week by logarithmic averaging; $L_{eq\ 24hr,d}$, Leq for a week by arithmetic averaging; $L_{eq\ ME}$, w , L_{eq} in each ME for a week by logarithmic averaging [a] Housewives, graduate and undergraduate students, and office workers were categorized into the lower exposure group. [b] The number of $L_{eq\ ME}$,w in each ME was equal to the number of $L_{eq\ 24hr,w}$. [c] For all groups, the median and range are represented at the bottom of the table Significant differences between the arithmetic mean of $L_{eq\ 24hr,d}$ and $L_{eq\ 24hr,w}$ for each participant was determined with a paired t-test ($p < 0.001$). The mean $L_{eq\ 24hr,d}$ was about 4 dBA lower than the mean $L_{eq\ 24hr,w}$ since a different calculation method was used, as shown in the Methods section. Increasing noise exposure resulted in larger differences between $L_{eq\ 24hr,d}$ and $L_{eq\ 24hr,w}$. In total, 177 of 318 (55.7%) $L_{eq\ 24hr,d}$ values were higher than the 70 dBA exposure limit recommended by the WHO and EPA. The mean $L_{eq\ 24hr,d}$ values during weekdays (72 dBA) were slightly higher than the mean $L_{eq\ 24hr,d}$ during weekends (70 dBA), but the results were not statistically significant. Only the industrial hygienist group had a significant difference in the mean $L_{eq\ 24hr,d}$ between weekdays (70 dBA) and weekends (65 dBA).

Noise exposure level in energy terms: sound exposure (SE,Pa^{2}hr).

Weekly occupational and nonoccupational noise exposure levels ($L_{eq,O,w}$, $L_{eq,NO,w}$) and sound exposure, which consider both time and exposure levels, are presented in Table 3-3. The mean L_{eq} level of 75 dBA during work time ($L_{eq,O,w}$) was not significantly higher than the 72 dBA during nonworking levels ($L_{eq,NO,w}$) on weekdays ($p = 0.155$). During work, the Korean traditional music apprentice group was exposed to the highest noise level (96 dBA) followed by service workers (80 dBA), firefighters (77 dBA), and heavy equipment operators (77 dBA). Industrial hygienists were not exposed to high levels because they mostly conducted routine periodic inspections in the industry for only a short time. Housewife occupational exposure occurred when they attended an open university, but the exposure time was short (Table 3-1).

Table 3-3. Weekly occupational and nonoccupational noise exposure levels ($L_{eq\ O,w}$, $L_{eq\ NO,w}$) and sound exposure (SE) by occupation.

Occupation	No.	Occupational exposure				Nonoccupational exposure			
		Dwelling time, %	Mean $L_{eq,O,w}$ (SD), dBA	Mean SE, Pa^2hr	Mean SE, %	Dwelling time, %	Mean $L_{eq\ NO,w}$ (SD),dBA	Mean SE, Pa^2hr	Mean SE %
Housewives	9	1.1	73 ± 3	0.0228	1.9	98.9	71 ± 4	1.1952	98.1
Graduate and undergraduate students	9	21.8	69 ± 4	0.1103	7.1	78.2	71 ± 5	1.4361	92.9
Office workers	6	39.7	68 ± 7	0.2606	6.3	60.3	77 ± 7	3.8782	93.7
Industrial hygienists	4	30.1	64 ± 7	0.1287	13.8	69.9	72 ± 2	0.8052	86.2
Service workers	3	22.8	80 ± 2	1.5557	40.3	77.2	73 ± 7	2.3030	59.7
Heavy equipment operators	4	23.4	77 ± 3	0.8450	18.2	76.6	77 ± 4	3.7941	81.8
Firefighters	7	49.9	77 ± 4	2.9596	79.8	50.1	72 ± 6	0.7505	20.2
Korean traditional music apprentices	5	11.9	96 ± 10	77.6860	91.1	88.1	78 ± 8	7.5468	8.9
Total	47	25.1	75 ± 10 75 [a)] (55–106)	9.3428	79.2	74.9	73 ± 6 72 [a)] (61–89)	11.7948	20.8

SD, standard deviaton; SE, sound exposure

[a)]Total median is also represented.

Noise levels during off-duty time ($L_{eq,NO,w}$) ranged between 71 and 78 dBA, but did not differ significantly among occupational groups (p = 0.06) and showed small differences among groups compared to the levels during on-duty time (SD 6 vs. 10 dBA, respectively). Office workers, industrial hygienists, and graduate and undergraduate students were exposed to higher noise levels during off-duty time compared to on-duty time. When considering sound exposure instead of exposure levels, interpretation of the exposure pattern could be significantly affected. The proportion of nonoccupational sound exposure was higher than occupational sound exposure in all groups, excluding firefighters and traditional music apprentices. For Korean traditional music apprentices and firefighters, the proportions of sound exposure in the workplace were 91.1 and 79.8%, respectively, while those in the other groups ranged between 1.9 and 40.3%. Also, much larger differences were observed when noise exposure was compared using sound exposure than when using equivalent continuous sound levels between occupational and nonoccupational exposure in most of the groups (excluding heavy equipment operators and housewives).

The largest percentages of time in all groups were spent at home (56.1%), followed by 24.2% at the workplace/school, 8.7% in other indoor settings, 4.9% outdoors, and 6.2% in transportation, as shown in Table 3-1. In contrast, the sound exposure of workplace/school contributed the most, while at home, sound exposure contributed the least to total sound exposure, as shown in Figure 3-2. The average contribution percentage of sound exposure in the workplace/school to total sound exposure by occupational group was the highest (32.0%), followed by other indoor (27.0%), outdoor (25.0%), transportation (10.3%), and at home (5.7%).

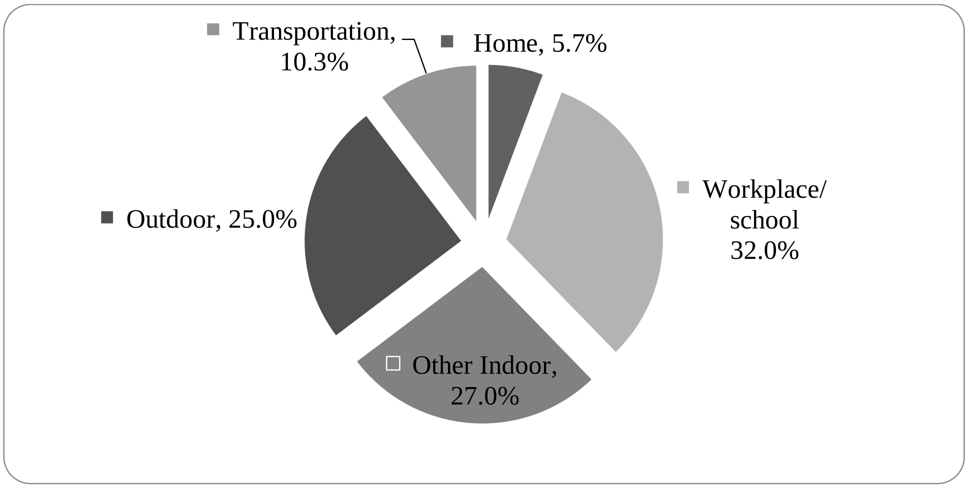

Figure 3-2. The average contribution percentage of sound exposure in each microenvironment to total sound exposure by occupational group.

The noise exposure differences among occupations were significant when compared using sound exposure (Pa^2hr) rather than equivalent continuous sound levels (L_{eq}). For example, Korean traditional music apprentices were exposed to a sound exposure during work that was 3,407 times higher than housewives (77.6860 vs. 0.0228 Pa^2hr). Although firefighters and heavy equipment operators were exposed to the same L_{eq} level (77 dBA) during work, firefighters were exposed to 3.5 times higher sound exposure than heavy equipment operators (2.9596 vs. 0.8450 Pa^2hr). On days off, Korean traditional music apprentices were exposed to the highest sound exposure, while firefighters were exposed to the least (7.5468 vs. 0.7505 Pa^2hr).

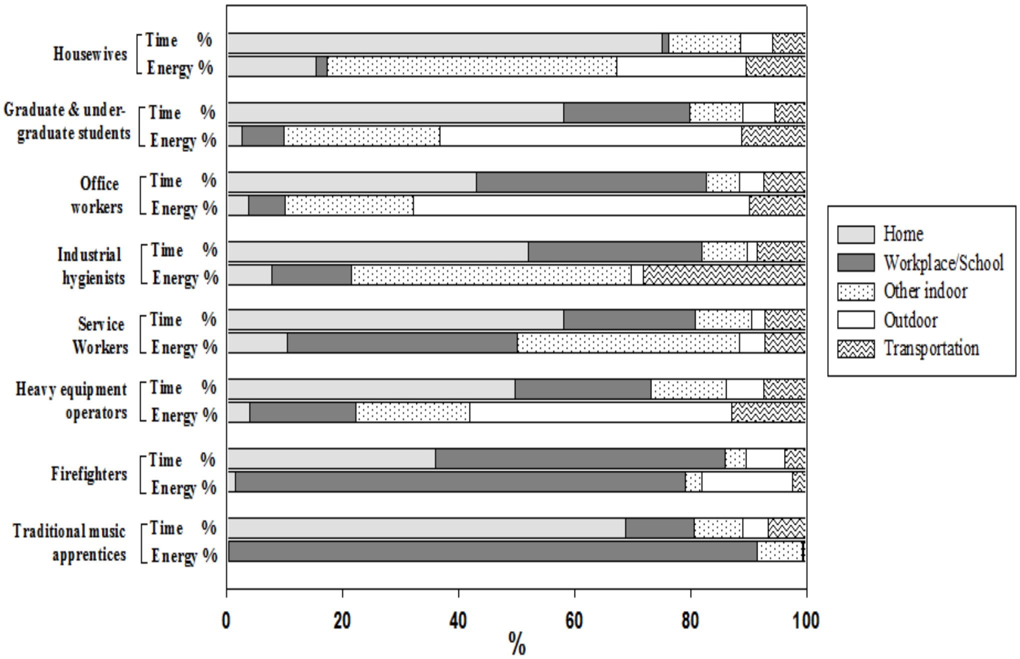

Figure 3-3. Comparison the percentage of time spent and the percentage of sound exposure to total sound exposure in each microenvironment by occupational group

Figure 3-3 compares the percentage of time spent and the percentage of sound exposure in each ME by occupational group. The percentage of time spent and the percentage of sound exposure in home differed significantly (p <0.001). The activity at home occupied the largest fraction of time (56.1%) but the smallest sound exposure (5.7%). The sound exposure ranged from 0.4% in Korean traditional music apprentices to 15.4% in housewives. The Korean traditional music apprentices, firefighters, and service workers were exposed to the high sound exposure (91.2, 77.7, and 39.7%, respectively) at the workplace/school while their time spent at the workplace/school was not significant (11.9, 49.9, and 22.8%, respectively). For the other five occupational groups, proportions of sound exposure were lower than the percentages of time spent at the workplace/school, although they were exposed to high sound exposure in other indoor, outdoor, and transportation environments. For office workers, graduate and undergraduate students, and heavy equipment operators, the contributions of sound exposure from outdoor environments were 57.9, 52.1, and 45.1%, respectively, which were related to noisy activities such as sports games, rock concerts, demonstrations, and walking on a noisy street. For example, four participants (graduates students, office worker, and 2 heavy equipment operators) attended a rock concert, sports game, field day event, and demonstration during the sampling period where they were exposed to 96, 95, 91, and 90 dBA L_{eq} for 3.9, 7.5, 6.3, and 6.7 hr, respectively, which accounted for 91.3, 85.2, 36.4, and 59.1% of their total weekly sound exposure.

The highest contribution of sound exposure from other indoor environments was 50.3% for housewives, followed by 48.3% for industrial hygienists and 38.7% for service workers, which were related to the ME in karaoke bars, health clubs, restaurants, churches, shopping malls, and hair salons.

We identified specific activities in the high noise group that may have contributed to the total sound exposure based on TAD analysis. For example, three participants (1 heavy equipment operator, 1 industrial hygienist, and 1 office worker) attended karaoke with their colleagues, where they were exposed to 89, 92, and 94 dBA L_{eq}, respectively, for 1 or 2 hr, which accounted for 28.8, 70.8, and 83.9% of their total sound exposure. One office worker was exposed to 92 dBA L_{eq} in a beer shop for 5.9 hr, which accounted for 41.8% of her total sound exposure. A housewife was in a health club with noise levels of 94 dBA L_{eq} for 1.8 hr, which accounted for 51.4% of her total sound exposure.

3.4. Discussion

This study was performed to evaluate the noise exposure levels of eight occupational groups over 24hr for 7 days in metropolitan Seoul. The percentages of measured $L_{eq\ 24hr,w}$ and $L_{eq\ 24hr,d}$ above the 70 dBA exposure limit (recommended by the WHO and EPA) were 80.9 and 55.7%, respectively, which suggests that individuals in this study are at risk of NIHL. The distribution of 47 weekly personal noise exposure levels ($L_{eq\ 24hr,w}$s) and 318 daily personal noise exposure levels ($L_{eq\ 24hr,d}$s) are presented in Figure 3-4, where the median value is 74 dBA, similar to the mean value of 75 dBA in Table 3-2.

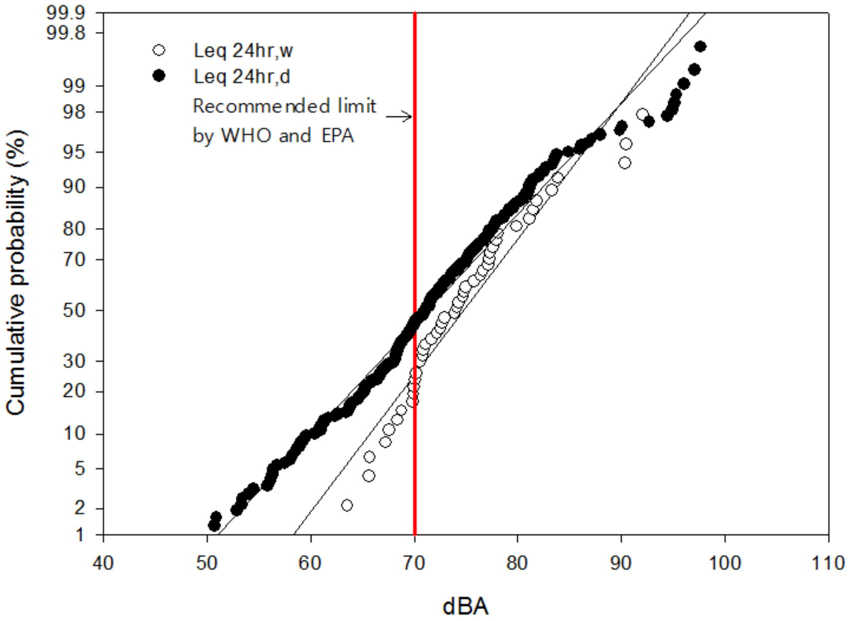

Figure 3-4. Cumulative distributions of 47 $L_{eq\ 24hr,w}$s (white circle) and 318 $L_{eq\ 24hr,d}$s (black circle).

Notably, a large portion of participants thought to be exposed to low noise levels in the workplace, school, or home were above the recommended limit by the WHO or EPA. For example, the percentage of housewives, students, and office workers over the 70 dBA $L_{eq\ 24hr,w}$ level were 66.7 (6 of 9), 44.4 (4 of 9), and 83.3% (5 of 6), respectively. Thus, nonoccupational noise exposure should be considered when we assess noise health hazards. These three occupational groups were exposed to nonoccupational SE 10 times higher than the occupational levels (Table 3-3). Some groups exposed to high levels of occupational noise were still significantly affected by nonoccupational noise exposure in terms of sound exposure. For example, the service workers, heavy equipment operators, and industrial hygienists were exposed to higher sound exposure levels in nonoccupational settings (Table 3-3).

Table 3-4. Summary of previous studies on weekly personal noise exposure monitoring

Authors	Subjects and monitoring periods	Results [a)]
Johnson and Farina (1977)	1 Worker (medical technician) for 31 days in the USA	L_{eq} for 31 days of 76 dBA
Schori and McGatha (1978)	50 persons (5 occupational groups) for 1 week in the USA	Mean $L_{eq(week)}$ of 73.3 dBA (median 74.7 dBA)
Berger and Kieper (1994)	20 persons for 1 week in the USA	Energy average (mean) $L_{eq(24)}$ of 78 dBA [b)] Arithmetic average (mean) $L_{eq(24)}$s of 75.8 dBA [c)]
Thompson et al. (2003)	19 persons for 1 week in the USA	The average 24hr Leq in all subjects was 76 dBA
Diaz and Pedrero (2006)	32 persons for 1 week in Spain	Mean of $L_{Aeq\ week}$ 74.9 dBA

[a)] The representative data related to the $L_{eq\ 24hr}$ results are presented as they appeared in the original text. [b)]Each personal noise exposure level was calculated using the same method (logarithmic averaging) with $L_{eq\ 24hr,w}$ in this [c)] Each personal noise exposure level was calculated using the same method (arithmetic averaging) with $L_{eq\ 24hr,d}$ in this study.

Limited data are available for weekly personal noise exposure measuring that contain both the occupational and nonoccupational settings. Previous studies on the weekly or longitudinal personal noise exposure are summarized in Table 3-4. These studies obtained mean values of 73.3–78 $L_{eq\ 24hr,w}$, [51 56-59] similar to the mean level of 75 dBA in this study. Those studies were performed after release of the EPA's "Levels Document" in 1974, which examined the levels of environmental noise necessary to protect public health and welfare, and established a yearly $L_{eq\ 24hr}$ limit of 70 dBA. The main purpose of those studies was to determine the number of people (at various ages and with different occupations) exposed to $L_{eq\ 24hr}$ of greater than 70 dBA. In those studies, the percentage of measured exposures above 70 dBA was about 80%, which was close to the 80.9% of the current study. The above-mentioned five studies were conducted in the Western world (4 in the United States and 1 in Spain), but no study on weekly personal noise exposure had been performed in Asia.[60-63]

Some controversy exists as to whether $L_{eq\ 24hr,d}$ or $L_{eq\ 24hr,w}$ is more appropriate to describe noise levels. Some studies have recommended $L_{eq\ 24hr,d}$ as representative of the individual noise exposure for 1 week because little difference was observed between the two descriptors. [58] If this were true under all circumstances, week-long noise exposure assessments would not be necessary. However, in this study, the difference between $L_{eq\ 24hr,w}$ and $L_{eq\ 24hr,d}$ was 3.7 dBA ($p < 0.001$), which corresponds to a twofold energy difference. This is similar to the results of Berger and Kieper's (1994) (75.8 vs. 78 dBA). $L_{eq\ 24hr,d}$ calculated by averaging the decibels for 7 days was based on the premise that the seven daily noise values were considered as seven independent estimates of a person's exposure. [51] In occupational settings, for the purposes of applying the exposure limit, weekly noise exposure level ($L_{ep,w}$) was recommended in place of daily noise exposure level to assess the noise levels which workers were exposed to when daily noise exposure varied markedly from 1 working day to the next.[1 64] In this study, 47 standard deviations were calculated from daily noise levels in each participant, which ranged from 2 to 16 dBA. A larger standard deviation among daily noise decibels in a participant represents a larger $L_{eq\ 24hr,w}$ compared to $L_{eq\ 24hr,d}$ ($r = 0.89$, $n = 47$, $p < 0.001$). The large standard deviation was mainly derived from episodic loud noise exposure, such as karaoke. Thus, including more episodic loud noise exposures is important to obtain accurate exposure measurements. This study suggests that $L_{eq\ 24hr,w}$ is more representative for comparison with the recommended $L_{eq\ 24hr}$ than $L_{eq24hr,d}$. In the same manner, measuring noise exposure for 1 year may be more accurate than measuring only for 1 week. However, the difficulty with a long-term study is accurately measuring exposures over short periods, and indirect approaches to assess exposure over longer periods must include episodic noise activities. The indirect approach was conducted by Neitzel et al. (2004a, b) to assess nonoccupational noise exposure of construction apprentices for 1 year ($L_{eq\ 6760hr}$), including routine and episodic noise exposure. The episodic noise exposures were determined from the published literature, and nonoccupational noise exposures of routine activities were measured using dosimetry along with activity cards for 32 construction apprentices. They used a novel noise index, $L_{eq\ 6760hr}$, for individual annual nonoccupational noise exposure levels. One of their main results was that the mean $L_{eq\ 6760hr}$ was 73 dBA, similar to the mean $L_{eq\ NO,w}$ of 73 dBA in this study (Table 3-3).

In this study, both direct and indirect exposure assessment approaches were applied. By combining personal exposure monitoring data using a dosimeter and TAD, which provided detailed contextual information on ME and noise sources, we could determine the contribution of each ME, including various sources and locations, as well as accurate exposure estimates from direct measurements. [65]

The sound exposure (Pa^2hr) was used to compare the contribution of each ME in this study. This unit expresses exposure to noise in absolute physical units, simplifying interpretation and calculation. With this unit, we could simply add the exposure at one ME to that of the exposure at another ME to obtain the total exposure. A study using a similar method was conducted to determine the contribution of different activities at different locations in Madrid, Spain (Diaz and Pedrero 2006). The authors reported that leisure activities contributed most to total sound exposure (64.6%), followed by transportation (12.6%) and the workplace (9.9%). The resulting contribution percentages of activities or locations differed from this study, although the average value for each of the participants during the week was similar (74.9 vs. 75 dBA). One of the major differences was the contribution rate of working to total noise (9.9 vs. 32.4%), followed by the contribution rate of leisure or recreation to noise (64.6%:51.5%), which may have been attributable to differences in the participant's occupation associated with occupational noise exposure and the percentage of time spent in the workplace (9.9%:24.2%). The sound exposure unit is easy to understand and simplifies comparisons of noise exposure levels by location or ME, but is not as applicable as the decibel scale.

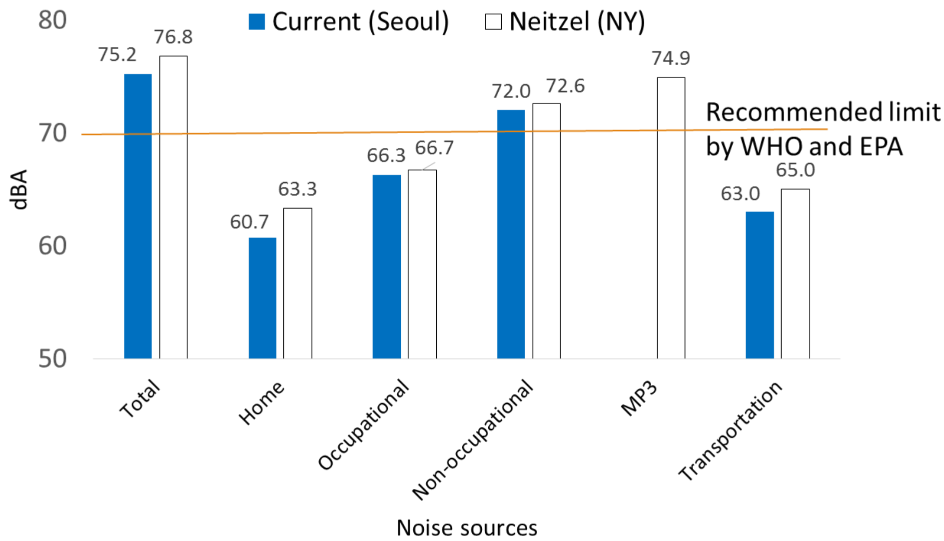

Figure 3-5. Comparison of normalized yearly noise exposure levels ($L_{eq\ 8760\ hr}$) of each source between current study and Neitzel et al's study in New York.

In this regard, a recent study did not apply sound exposure but normalized yearly noise exposure levels ($L_{eq\ 8760\ hr}$) of each source compared to the relative contribution of the five sources of exposure to total exposure. [66] Normalization of noise levels was performed to treat noise exposure from each source as though it was the only noise exposure that occurred during a 1-year interval. Each $L_{eq\ 8760hr}$ in the noise source can be directly compared with the recommended limit of 70 dBA, which provides us with information regarding potential health effects. The five noise sources in the study by Neitzel et al. (2012) were similar to the five MEs in this study as shown in Figure 3-5. After normalization, our $L_{eq8760hr}$ noise exposure levels in specific environments, as well as classification of noise sources, were similar, with occupational levels of 66 dBA vs. 66.7 dBA (transit users) and nonoccupational levels of 72 vs. 72.6 dBA (transit users) in our study and the study by Neitzel et al. (2012), respectively. In both studies, time spent at home accounted for the vast majority of hours for most participants, but contributed a very small fraction to the total exposure because of the low noise levels. Nonoccupational sources or MEs (excluding home) in both studies contributed more to total sound exposure due to the high noise levels and long dwelling time. However, some differences were observed in the percentage exceeding the noise limit of 70 dBA (90 vs. 80.9%) and total annual noise exposure (76.8 vs. 75 dBA) in our study compared to the study by Neitzel et al. (2012), respectively. These differences could be explained by the fact that this study did not consider direct transfer from noise to the inner ear (such as an MP3 player), and annual average MP3 player exposures were reported to increase noise levels by 1 dBA among transit users in previous studies. Also, 16% of participants in this study reported using earphones while listening to music from a smart phone. No participants wore hearing protection devices during measurement. Thus, the actual exposure levels are slightly higher than the reported values. However, this study has some limitations. For example, this sample cannot be generalized to noise exposure of the Seoul population because it was not randomly selected but instead limited to specific occupations. However, the time activity patterns were similar to other studies on civil servants in Seoul (home 53.2 vs. 56.1%, workplace 27.3

vs. 24.2%, other indoors and outdoors 13 vs. 13.6%, and transportation 6.1 vs. 6.2% in this study and previous studies, respectively), suggesting that our sample is representative of Seoul citizens aged 20–50 years. [67] In this study, we could not exclude a participant's own voice, which can contribute to the noise exposure because of technical issues with measurements. Previous studies reported that about 5 dB was contributed to the total noise level by a person's voice in medium-level noise environment.[68 69] In this study, we attached a microphone of dosimeter just below the ear to avoid the participants own voice, but some effects were inevitable. Lastly we did not measure the instantaneous peak sound pressure level because there are no validated models for integrating peak levels. [20 70]

3.5. Conclusions

We found that 80% of all participants were exposed to noise over the recommended limit of 70 dBA. Also, 60% (15 of 24) of participants with an occupation thought to have low noise exposure were still over the recommended limit. Noise levels below those measured in this study pose nonauditory risks including stress, hypertension, and cardiovascular disease. [71] This suggests that many people who live in the Seoul metropolitan area may be at risk of NIHL and other nonauditory health effects.

Furthermore, the mean nonoccupational noise exposure level of all participants (72 ± 6 dBA) that normalized to a nominal 24 hr or 8760 hr was over the recommended limit, which means that nonoccupational noise exposure may not be negligible. Thus, further studies using direct and indirect methods based on a larger number of participants are required.

Chapter 4.

Task-specific noise exposure assessment of firefighters

This chapter was presented in American Industrial Hygiene Association Conference and Exposition (AIHCe) (2013.05.23)

4.1. Introduction

Firefighters are commonly exposed to short-term, intermittent, high-intensity noise, unlike the continuous noise levels found in manufacturing and other workplaces. Noise induced hearing loss (NIHL) is the most underrated health problem impacting firefighters. Some previous research has suggested that firefighters' hearing threshold levels (HTLs) decline faster than expected during their careers compared with age-matched members of the general population.[72-76]

Collecting noise-exposure data in firefighters' workplaces is obviously difficult, given the unpredictable locations and dangerous and rapidly changing environment. Thus, while many previous studies used noise measurements over short periods of time during noisy work activities, full-shift measurements have rarely been carried out, and those that have been conducted was limited in North America. Studies by the US National Institute for Occupational Safety and Health (NIOSH) found that although firefighters were intermittently exposed to high peak noise levels during emergency responses, when noise exposure levels were averaged out over working shifts, they were below the recommended occupational exposure limit.[77-79] Little further research on firefighters' noise exposure has been conducted.

However, contrary to expectations, recently released papers have reported that shift-adjusted noise exposure levels are much higher than those measured previously by NIOSH, which rarely exceeded 85 dBA.[80 81] These studies suggested that some tasks were associated with noise levels high enough to present a risk of NIHL with chronic exposure, although some potential 24-h exposures showed substantial imprecision.[81]

Few studies have been conducted in Asia exploring noise exposure in firefighters.[82] In particular, noise-exposure measurements with time and task information are needed because firefighters are exposed to intermittent high noise levels, and weekly noise exposure measurements are recommended for occupations where noise exposure varies markedly from day to day.[1 64]

Thus, the purpose of this study was to evaluate firefighters' daily personal noise exposure and to investigate the noise levels associated with specific tasks and their contributions to total noise exposure by 24 hr full-shift noise-exposure assessments with task-based information.

4.2. Materials and methods

Noise exposure assessment with task-based information

We collected personal noise samples at 2 departments in during September 2010 and September 2011. 8 firefighters, who were 4 firefighters from each department with 2 suppressor, 1 rescuer and 1 driver, were selected. 2 of 4 suppressors were classified into investigator, who generally has an experience of over 10 years of suppressor. Paramedic was not sampled because dosimeter set got in the way of their work with patients. Sampling were conducted for three duty cycles (24hr) per subject. There were altogether 24 samples; 6 in two rescuers, 6 in two drivers and 12 in 4 suppressors including 2 investigators. Each firefighter wore data-logging dosimeters (model 706 RC; Larson Davis, Provo, UT) 3 times (24hr shift) over a week, because alternating 24-hr shift was most common in field personnel. The sampling period ranged from September 2010 to September 2011. Data used in the current analysis were 1-min sound pressure levels (1-min L_{eq}) in decibels (dB) recorded using the criteria set forth in the ISO/NIOSH: "A" frequency weighting and a 3-dB exchange rate. During the measurement, they were required to complete time-activity diary (TAD), which has a free field to log their area and activities. Data were downloaded to the Blaze software program (Blaze; Larson Davis, Provo, UT, USA) and exported to Excel 2007 (Microsoft, Redmond, WA) to calculate the noise descriptor. Full shift noise exposure levels were represented with $L_{ep,d}$ shift-adjusted daily personal noise exposure level. The $L_{ep,d}$ is normalized over an 8-hour period, also known as Lex,8h in ISO/NIOSH, which can be calculated using following Equation (1) :[64 83]

$$Lep,d = Leq,_{Te} + 10 \log \left(\frac{Te}{T0}\right) \qquad (1)$$

where T_e is the effective duration in hours (about 24 hours in this study), and T_0 is the reference duration (8 hr) [83]. The weekly personal noise exposure, $L_{ep,w}$, for a firefighter was calculated using eqation (1) for a weekly working hours (maximum 72 hours). Thus, 8 $L_{ep,w}$ values with 24 $L_{ep,d}$ were obtained.

Activity information from TAD was categorized into the 5 major activities (call, checking, office work, waiting, others). The diary and recorded data were checked every day, during the sampling period by a researcher. Approximately 1456 measurements, taken every minute for a 24hr-shift, were recorded by real-time monitoring during the sampling period. To calculate the noise levels of the specific tasks, log data of the TAD and their corresponding 1-min L_{eq} level data were aggregated by firefighter, and task-specific L_{eq} values ($L_{eq\ activity}$) for each firefighter were calculated using Equation (2):

$$Leq_{Activity_{ij}} = 10 \log_{10} \frac{1}{n_{ij}} \sum_{k=1} 10^{Leq_{ijk}/10} \qquad (2)$$

where n_{ij} is the number of minutes that a firefighter i is in activity j and $L_{eq\ ijk}$ is the SPL (Sound pressure level) recorded for firefighter i and activity j during a 1-min noise interval k. The activity specific L_{eq} values were combined to calculate the mean L_{eq} for each activity.

The contribution of total noise exposure levels in each activity was evaluated by sound exposure (SE; pa^2hr), which can be determined from Equation (3) [25]:

$$SE\ Activity_{ij} = (\ p_{ref}^2 T\ ) \times 10^{\frac{Leq\ Activity\ _{ij}\ ,T_{ij}}{10}}\ Pa^2 hr, \quad p_{ref} = 20\mu Pa \quad (3)$$

where T is the time of each activity in hours, I and j are same to Equation (1).

Descriptive statistics were used to display the results of the subject noise levels and characteristics (time spent during each activity). Data were assessed for normality. Arithmetic means and standard deviations were used to describe central tendency and variation in each main role because the noise levels ($L_{ep,d}$, $L_{ep,w}$) were normally distributed according to the Shapiro-Wilk test. The same statistics were used to describe noise exposure level ($L_{eq\ activity}$, $SE_{\ activity}$) and time spent in each activity for consecutive 3 day shift work per subject, although it can’t be tested for normality because of the small sample size (2 per main roles). ANOVA test were performed to compare $L_{ep,d}$ among main roles in firefighter. Student's t-test was used for comparison of $L_{ep,d}$ between two stations, and paired t-test by pairing data at each main role was performed to control dependency of main role. The paired t-test was also used to evaluate the differences between averages ($L_{ep,d}$ vs $L_{ep,w}$) of each firefighter. SAS v 9.3 was used for all statistical analyses including audiometric test data. The methods of personal noise measurement was illustrated in more detail elsewhere.[84]

4.3. Results

Noise exposure level of firefighters

Noise data were obtained for eight firefighters in three main roles (rescuers, drivers, and suppressors). Mean age and years of service for the eight participants were 39 and 11.5 years, respectively. We obtained a total of 24 valid full-shift personal noise sample data sets (three samples per participant). Daily firefighter noise exposure level, "$L_{ep,d}$" was calculated using Equation (1), and a summary of the findings is presented in Table 4-1. As shown in Table 4-1, the overall noise exposure level was 81.7 dBA, ranging from 70.6 dBA for a suppressor (investigator) to 94.8 dBA for a rescuer. The highest mean level of noise exposure was for the rescuer (84.6 dBA), followed by the driver (83.3 dBA), and suppressor (79.5 dBA). A significant difference was observed among main roles, as determined by one-way ANOVA ($p = 0.04$), which was not the case among fire departments, analysed using the *t*-test and paired *t*-test ($p = 0.87$, $p = 0.88$, respectively). Of the 24 samples, five (20.8%) showed levels of noise exposure greater than $L_{ep,d} = 85$ dBA, the upper exposure action value (UEAV) in the UK; three of six (50%) data sets from rescuers showed values above the UEAV.

Table 4-1. Daily personal noise exposure level (dBA) of firefighters by the main role

Main role	N	Sampling time, hour	$L_{ep,d}$, dBA	*P*	N of UEAV [a)] exceedance
		Mean (SD)	Mean (SD)		
Rescuer	6	24.4 (0.1)	84.6 (6.2)	P=0.04	3
Driver	6	24.1 (0.5)	83.3 (2.7)		1
Suppressor	12	24.3 (0.3)	79.5 (3.5)		1
Total	24	24.4 (0.4)	81.7 (4.6)		5

N, number (of 24hour noise samples); SD, standard deviation. [a)]UEAV, Upper exposure action value ($L_{ep,d}$=85 dBA) in the Control of Noise at Work Regulations UK 2005

Table 4-2 shows more detailed information on the firefighters' weekly activity and personal noise-exposure levels. In total, recordings were made of 35148 min (101.7%) of 34560 min of work for eight firefighters (3 days of 24-h shift work per subject) during the survey. With simultaneous dosimetry, noise levels (35148 1 min-L_{eq}), 8 $L_{ep,w}$ and 40 task-specific L_{eq} values ($L_{eq,\ activity}$) over five main tasks from the eight participants were calculated.

The $L_{ep,w}$ range varied from 78.7 to 91.3 dBA, with a mean of 82.4 dBA (standard deviation, SD = 4.2 dBA). The mean of $L_{ep,w}$ was higher than the mean of $L_{ep,d}$ (81.7 dBA; $p = 0.025$), and the variability of $L_{ep,w}$ was lower than that of $L_{ep,d}$ (SD = 4.6 dBA). The rescuer was exposed to the highest mean level of weekly noise (85.5 dBA), followed in order by the driver (83.8 dBA) and suppressor (80.2 dBA). When suppressors were classified into two groups by activity, i.e., between suppressor and investigator, investigators were exposed to less noise (81.2 vs. 79.3 dBA).

The firefighters' five main activities took place in the field or at the station. They spent the largest overall percentage of time in the station (88.8%) doing tasks such as waiting (44.1%), working in the office (31.8%), checking equipment (5.3%), and other (7.6%). Firefighters' mean percentage of time spent on call was much less than that spent at the station (11.2%), but the average Leq during response to a call (84.1 dBA) was higher than that in the station (73.3 dBA). The mean contribution of SE on calls to total SE was relatively similar to that for the ratio of time at the station because SE is a function of L_{eq} and time spent as shown in Equation (3). The highest total average L_{eq} was measured in checking (86 dBA), followed by doing task-related calling regarding an emergency (84.1 dBA), other including eating and exercising (74.5 dBA), working in the office (69.6 dBA), and waiting in the break room (63.3 dBA; $P < 0.001$). In terms of sound exposure considering $L_{eq\ activity}$ and exposure time, the average contribution of activity in responding to calls was the largest (45.6%), followed by checking equipment (36.7%), working in the office (7.5%), other activities (5.1%), and waiting in the break room (5.0%). Despite the small fraction of time spent (5.3%), checking equipment occupied the largest fraction of SE (45.6%), and the SE of activity on call to total SE was 45.6% during a relatively short period (11.2%). Checking equipment and responding to calls accounted for most of the SE (82.3%).

Waiting in the break room, mainly at night, occupied the largest fraction of time (44.1%), but the SE was small (5.7%). The time spent working in the office during periods between emergency responses, mainly in the daytime, was 31.8% of weekly working hours, but the mean ratio of SE to total exposure was only 7.5%. Rescuers were exposed to the highest noise levels during checking equipment including powered saws, pneumatic chisels and hydraulic spreaders which was over half of their total noise exposure (SE), despite comprising only about 2% out of their total work time. Rescuers spent more time on emergency responses than did suppressors or drivers because emergency calls for rescues were over five times more frequent than emergency calls for fires.[85] Drivers were exposed to an average L_{eq} of 88.3 dBA while responding to calls, which was 53.9% of their total noise exposure (SE), despite the fact that this activity consumed only about 7% of their total work time. Drivers spent more time checking equipment compared with firefighters in any other role because it took more time to check the vehicles than to check other equipment.

Table 4-2. Firefighters' weekly personal noise exposure with task-specific level

Main role of firefight-er	N	Total		Call			Station											
							Checking			Working in office			Waiting			Others		
		Time	Noise	Time	Noise		Time	Noise		Time	Noise		Time	Noise		Time	Noise	
		Mean of Hours (SD)	Mean of $L_{ep,w}$ [a] ,dBA (SD)	Mean of % total time (SD)	Mean of L_{eq} ,dBA (SD)	Mean of % total SE (SD)	Mean of % total time (SD)	Mean of L_{eq} ,dBA (SD)	Mean of % total SE (SD)	Mean of % total time (SD)	Mean of L_{eq} ,dBA (SD)	Mean of % total SE (SD)	Mean of % total time (SD)	Mean of L_{eq} ,dBA (SD)	Mean of % total SE (SD)	Mean of % total time (SD)	Mean of L_{eq} ,dBA (SD)	Mean of % total SE (SD)
Rescuer	2	74.2 (2.5)	85.5 (8.1)	22.1 (12.8)	82.2 (4.7)	42.8 (45.6)	3.5 (2.1)	91.4 (16.2)	52.1 (51.5)	34.4 (16.9)	67.1 (2.2)	1.6 (1.2)	33.3 (2.0)	62.0 (1.4)	1.0 (1.3)	6.6 (3.9)	73.7 (2.5)	2.4 (3.0)
Driver	2	73.2 (0.8)	83.8 (2.1)	7.0 (4.4)	88.3 (1.4)	53.9 (7.7)	11.6 (8.5)	84.8 (6.3)	37.9 (5.7)	25.1 (7.7)	69.9 (3.0)	3.3 (1.6)	44.8 (9.3)	64.1 (1.0)	1.7 (1.4)	11.5 (5.7)	73.3 (2.3)	3.1 (1.7)
Supress-or	2	73.2 (0.3)	81.2 (2.1)	9.0 (3.3)	81.0 (2.0)	26.0 (9.4)	3.9 (1.2)	87.1 (1.4)	45.5 (7.7)	19.9 (4.3)	71.9 (4.0)	7.7 (4.7)	59.2 (10.1)	65.2 (7.7)	12.8 (17.0)	8.0 (1.3)	76.1 (1.5)	8.1 (4.9)
Investi-gator	2	72.4 (1.5)	79.3 (0.9)	6.9 (5.7)	84.8 (3.4)	60.0 (2.4)	2.3 (0.5)	80.5 (2.5)	11.4 (7.8)	47.6 (3.6)	69.9 (2.6)	17.6 (8.1)	38.9 (14.4)	62.9 (4.6)	4.6 (5.3)	4.3 (4.6)	76.0 (1.5)	6.5 (7.4)
Overall	8	73.2 (1.3)	82.4 (4.2)	11.2 (8.8)	84.1 (3.8)	45.6 (22.6)	5.3 (5.2)	86.0 (7.9)	36.7 (25.9)	31.8 (13.4)	69.6 (3.0)	7.5 (7.6)	44.1 (12.8)	63.3 (3.5)	5.0 (8.4)	7.6 (4.2)	74.5 (2.4)	5.1 (4.4)
							88.8 [b] (8.8)	73.3 [b] (2.5)	54.4 [b] (22.7)									

N, number (of firefighters who participated in noise sampling); SE, sound exposure (Pa^2hr), SD, standard deviation

[a] Weekly personal noise exposure with logarithmic averaging of 3 $L_{ep,d}$ of a firefighter. [b] Total noise exposure in Station including Checking, Office, Waiting and Others (cafeteria etc.)

4.4. Discussion

This study focused that most firefighters were exposed to higher than recommended exposure at a low-action value of $L_{ep,d}$ = 80 dBA, indicating that they are at a risk of NIHL, and noise-control efforts are needed. Noise measurements were combined with time-at-task information to represent noise exposure, which showed that 82.3% of SE occurred while checking equipment and responding to fire or emergency calls.

The mean shift adjusted daily personal noise exposure level in this study was similar to that found by Kirkham et al.(2011), who examined Canadian firefighters ($L_{ep,d}$ = 82.9 ± 4.4 vs. 81.7 ± 4.6 dBA). They reported that exposure levels did not differ by job title, but they showed significant differences in supervisory compared with non-supervisory firefighters. We measured only non-supervisory firefighters, and unlike Kirkham et al.,[80] we found that noise exposure levels differed significantly with main role. They suggested that interventions should focus on the activities of checking hand tools or SCBA for short periods, which was scientifically demonstrated by the analysis of task-specific sound exposure levels in this study.

Task-specific full shift noise exposure assessment for firefighters was first attempted by Neitzel et al. to develop task-based methodologies for firefighting operations. They measured noise levels as well as time spent per task in a 24-h shift. Their results are similar to ours in the patterns of time spent (call time:

station time = 9.8%: 90.2% vs. 11.2%: 88.8%), but show slight differences in noise doses for each task (call: station = 67%: 33% vs. 45.6%: 54.4%). In this study, the proportion of noise exposure (SE) during checking equipment at the station was higher. The mean 24-h personal noise exposure level ($L_{eq\ 24hr}$ = 84.5 ± 2.4) was much higher in Neitzel et al (2012).'s [81] study than in ours ($L_{eq\ 24hr}$ = 77.0 ± 4.6); all (5/5) of their results were above the NIOSH REL criteria ($L_{eq\ 24hr}$ = 80.25) compared with 21% (5/24) of our results.

This study suggests how effective control could be implemented in the field. For example, if rescuers were provided with hearing-protection devices and used them for only about 50 min during checking equipment, over 50% of the noise dose (SE) would be avoided. Previous studies have documented similar results, [80] but the current study provides the first quantitative data with SE. Full-shift noise exposure assessments with task-based information are hard to conduct but can provide much valuable information for controlling noise, particularly in jobs characterised by high variability and intermittency, such as firefighting.

This exposure assessment has some limitations. The main limitation is the small sample size, which limits the generalizability of the results. In future studies, the sample should be larger and should include paramedics and supervisory firefighters. The exposure data reported in this paper were obtained from a few fire departments in the Seoul area. Thus, the findings may not be applicable to other fire departments in different regions of South Korea.

4.5. Conclusions

These results showed that firefighters are at a risk of NIHL, and noise-control efforts are needed. This task-specific noise exposure assessment also represented that more efforts should be made to control the noise exposure during checking equipment and responding to emergency call.

Chapter 5.

Hearing among male firefighters: A comparison with hearing data from screened and unscreened male population

This chapter was presented in American Industrial Hygiene Conference and Exposition (AIHce) (2013.05.23).

5.1. Introduction

Firefighting is one of the most hearing critical occupations. The hearing health of firefighters concerns much more than hearing conservation.[86 87] Hearing is crucial in preventing injury in the firefighting environment, where smoke often minimises visual cues, and high levels of background noise and stress-related distraction are present.[86] Firefighters should have adequate hearing acuity to hear a victim scream for help, to hear the low-pressure alarm from a self-contained breathing apparatus (SCBA) indicating that the device is running out of air, to hear sounds associated with imminent collapse, and to hear noises associated with changes in a fire pattern.[86]

Noise is a part of the causal mechanism leading to hearing injury and can cause hearing loss.[88 89] Firefighters are exposed intermittently to high-intensity noise. However, firefighters tend to accept noise exposure as inevitable. In particular, during responding emergency call, firefighters' serious health risks are ignored.[90]

Some previous researches have suggested that firefighters' hearing threshold levels (HTLs) decline faster than expected during their careers compared with age matched members of the general population.[72-75] However, a recent US study using data from hearing conservation programs in two fire departments suggested that firefighters were not at risk for occupational noise induced hearing loss. This may have been the result of the implementation of hearing conservation programs starting in the 1980s.[91]

There are about 38,000 career firefighters in Korea. In 2011, their fatality rate was over three times that in the US (2.2 in 10,000 in Korea vs. 0.61 in 10,000 in the US). Korean firefighters' weekly average working time is longer than that of US firefighters, by approximately 30 h, but little is being done to protect them.[85 92]

Korean fire departments do not have hearing conservation programs. No baseline audiograms are recorded, and hearing protection devices are not provided. Also, until recently, few studies have been conducted in Asia exploring hearing levels in firefighters.

Thus, the aim of this study was to investigate whether hearing loss is associated with a firefighting career in Korea. A cross-sectional study was conducted: comparisons of hearing thresholds of firefighters with two age matched population-based data sets (one from a group of otologically screened normal Korean males with no noise exposure (KONP) and one from a group of unscreened Korean males who had not been exposed to occupational noise (KNINEP))

5.2. Materials and methods

Subjects and source data

The subjects of this study were a total of 912 male firefighters who worked in 4 of 23 local fire departments in Seoul, Korea. The four fire departments (Guro, Mapo, Gwanak, Gwangjin) were randomly selected after dividing Seoul into four sectors. Firefighters' age ranged from 24 to 59 (mean age=44). The study included male firefighters only because of small numbers of females (5%) in fire service. Since 2004, the annual **a**udiometric testing for firefighters has been performed in three hospitals that were approved by the Korean Ministry of Employment and Labor. A standard pure tone audiometric testing was conducted at frequencies at .5, 1, 2, 3, 4, 6 kHz for both ears. HTLs were reported in 5-dB increments and hearing threshold levels (HTLs) were obtained between -10 and 90 dB.

This study used 2010 audiometric data of the firefighters that were obtained from the participating fire departments. Audiometric data included HTLs measured at test frequencies from 0.5 kHz to 6 kHz, along with the participant's age and lengths of service. The service duration was coded by month of each main role such as a fire suppressor, rescuer, medical paramedic, driver and office job. Firefighters are divided into field personnel and office personnel. Fire suppressors, rescuers, paramedics and drivers are categorized into the field personnel. The office personnel are responsible for enforcing laws or regulations related fire prevention. In general, firefighters are assigned to one major job task at the beginning of their career but occasionally often they get rotated to different job tasks.

There were no personal identifiers recorded in the database. The study protocol was approved by the institutional review board (IRB) of the Graduate School of Public Health in Seoul National University, South Korea.

The screened and unscreened population for comparison

Firefighters' hearing status was compared with two hearing database of general population in Korea: 1) KONP (Korean otologically normal population); and 2) KNINEP (Korean nonindustrial noise exposed population). The KONP is hearing data obtained from otologically normal healthy adults with no noise exposure .The KONP included a total of 2,492 adults (male= 1,250, female=1,242) with approximately 60 subject (male 30, female 30) in each of one year age groups from 20 to 59.93 About 80% of the KONP participants were from Seoul area, the capital city of South Korea. KONP hearing data consisted of HTLs of both ears at frequencies of.5, 1, 2, 3, 4, 6 and 8 kHz. The standard pure tone audiometric testing was performed in 8 hospitals that were approved by the Korean Ministry of Employment and Labor. The tests were conducted with the calibrated audiometers at 2 dB steps either in the sound-treated fixed booth or in the portable booth, which was positioned in a site where the American National Standards Institute (ANSI) standard for background noise was met.94 HTLs were obtained between -10 and 90 dB. The HTLs at frequencies (.5, 1, 2, 3, 4 and 6 kHz) of 1,130 male, aged from 24 to 59 out of entire KONP HTLs DB were selected for comparison. Because 453 of subjects were not measured at 3000 kHz in some hospitals, 677 subjects' data were used for calculating PTA1234, averaging hearing thresholds at frequencies with 3 kHz. Second comparison data are taken from the fifth KNAHNES (Korean National Health and Nutrition Examination Survey) that was collected from 2011.95 KNAHNES data included survey data on health and nutritional status among general population in Korean. The subjects of KNAHNES were chosen through a stratified multistage probability sampling procedure to serve as a nationally representative sample. The data included audiometric hearing tests and interviews of 6,302 subjects over 12 years old. Audiometric tests were performed at a mobile audiometry booth using a microprocessor pure tone audiometry in both ears at frequencies of .5, 1, 2, 3, 4 and 6 kHz in 5-dB increments. HTLs were obtained between -10 and 90 dB. For the purpose of comparison, we selected hearing data of 1,231 males (mean age=43, ranged from 24 to 59) who answered 'no' to the question: 'Have you ever been exposed to loud noise emitted from machine or generator for at least three months in workplace? Loud noise means noise was so loud that you had to speak in a raised voice to be heard'. We named this unscreened general population KNINEP because subjects were not screened for any nonoccupational noise exposure or otological diseases.96

Prevalence ratio and odds ratio of hearing loss in firefighters versus general populations

There are several definitions of hearing impairment. In the occupational setting, hearing impairment is generally defined as a pure tone average (PTA) of the HTLs for both ears that exceeds 25 dB at 1000, 2000, 3000, and 4000 Hz (PTA1234).97 We used it as a definition of hearing loss for comparison. The number of subjects from three groups exceeding these criteria for the average of the both ears was calculated. Hearing loss was calculated by main roles of firefighter and five age groups. Prevalence ratio (PR) of hearing loss among firefighter and each general population was calculated by Cochran-Mantel-Haenszel method, stratified by 5 age groups.

Association of hearing loss and main role month was examined by generalized linear model (log link, Poisson distribution) controlling for age as a continuous variable. The prevalence ratios were calculated for firefighters, using each general population as reference group. All reported p values were two tailed, and $p < 0.05$ was established as the level of significance.

Comparison of firefighters' HTLs with the screened and unscreened population

Medians and selected other percentiles are commonly used to describe audiometric threshold distributions because HTL distributions of population-based samples are usually positively skewed.98 For each test frequency and age group, medians and 90 percentile of HTLs for Korean firefighters were compared with those from two comparison groups. For the purpose of comparison, five age groups were used: 24-30, 31- 40, 41- 45, 46- 50, and old than 51 years. The table for comparison of three groups' threshold levels consists of 60 cells, for each cell has median or 90 percentile threshold level of each frequency and age group. For each comparison cell, the HTLs of firefighters were judged as "better than," "not different from," or "worse than" KONP or KNINEP. To clarify the comparison, the medians with 95 percentile upper and lower confidence intervals for firefighters' HTLs were represented with those of KONP and KNINEP by audiogram.

5.3. Results

Prevalence ratio of hearing loss in firefighters versus general populations

Table 5-1 shows the prevalence and prevalence ratio of hearing loss (PTA1234 $\geq$ 25 dB) among firefighters and general populations. The average age of the 912 firefighters was 44 $\pm$ 8 years, which was not different from those of the comparison groups (44 $\pm$ 11 years in KONP, 43 $\pm$ 10 years in KNINEP). The HTLs of 1, 2, 3, and 4 kHz were averaged for the left and right ears of each subject (PTA1234). About 16.3% of firefighters had hearing loss, compared with 3.4% of KONP and 17.6% of KNINEP. Controlling for the age effect (presbycusis), the prevalence of hearing loss in firefighters and in KONP was compared using the Cochran–Mantel–Haenszel test. This yielded a prevalence ratio of hearing loss for firefighters versus the general populations, with the age groups stratified as above. The prevalence ratio for firefighters versus KONP was 5.29 (3.34–8.39; $p < 0.001$), and that for firefighters versus KNINEP was 0.99 (0.95–1.02; $p = 0.444$).

Table 5-1. Prevalence and prevalence ratio of hearing loss among firefighter and control groups

	Firefighter						KONP [a]	KNI-NEP [b]
	Rescuer	**Paramedic**	**Driver**	**Suppressor**	**Office worker**	**Subtotal**		
N	93	101	261	318	139	912	677	1231
Age (years) (Mean±SD)	39±7	39±7	44±8	45±7	46±8	44±8	44±11	43±10
N of HL[a] subject (%)	24 (25.8%)	14 (13.9%)	36 (13.8%)	52 (16.4%)	23 (16.6%)	149 (16.3%)	23 (3.4 %)	216 (17.6%)
PR [b]	Firefighters / KONP					5.29	(3.34 ~ 8.39, p<0.001)	
	Firefighters / KNINEP					0.99	(0.95 ~ 1.03, p=0.550)	

N, number (of firefighters); KONP, otologically normal male Korean population nonindustrial-noise-exposed population database; KNINEP, Non-industrial noise-exposed male Korean population; PR, prevalence ratio
[a] hearing loss : PTA1234≥ 25 dB [b] prevalence ratio calculated by the Cochran-Mantel-Haenszel test adjusting age strata

In terms of the major roles of firefighters, hearing loss was most prevalent in rescuers (25.8%), followed in order by office workers (16.6%), suppressors (16.4%), paramedics (13.9%), and drivers (13.8 %). The Cochran–Mantel–Haenszel test among the main roles of the firefighters, adjusting for age, demonstrated significant differences among the roles ($P = 0.030$).

Table 5-2 shows the prevalence ratios of hearing loss in firefighters compared with KONP, which is the result of generalized linear model (log link, POISSON distribution) for hearing loss in firefighters and KONP, combined with age and years of service for each main role of the firefighters. The service duration of all main role were significant predictor of hearing loss, in particular, that as rescuer showed the highest risk (PR=1.010, p<0.001) than that as any other main role. Although age was the strongest predictor as well, age effect became insignificant after service duration of main role had been entered into the regression equation (PR=1.022, p=0.0625).

Table 5-2. Results of generalized linear model (log link, Poisson distribution) for hearing loss in firefighters (N=912) and KONP (N=677) combined age and service duration as a firefighter

	PR	CI	β	SE	p
Service Duration (month) as a main role :					
Rescuer	1.010	1.007~1.013	0.0101	0.0015	< 0.0001
Paramedic	1.006	1.003~1.012	0.0064	0.0019	0.0008
Driver	1.004	1.002~1.006	0.0046	0.0010	< 0.0001
Suppressor	1.004	1.002~1.006	0.0039	0.0011	0.0001
Office worker	1.004	1.001~1.006	0.0038	0.0014	0.0012
Ref [a)] (N=677)	1.000				
Age (year)	1.022	0.9989~1.051	0.0217	0.0115	0.0625

PR, Prevalence ratio; CI, Confidence interval (95%).
[a)] Reference group is the KONP with no service duration as a firefighter.

The result of generalized linear model (log link, POISSON distribution) for hearing loss among firefighters and KNINEP is shown in Table 5-3. Prevalence ratios for hearing loss increased with age (RR = 1.077, 95% CI: 1.063–1.091). Duration of service (month) in the role of a rescuer was the only significant predictor of hearing loss after adjusting for age (RR = 1.005, 95% CI: 1.002–1.007).

Table 5-3. Results of generalized linear model (log link, Poisson distribution) for hearing loss in firefighters(N=912) and KNINEP (N=1231) combined age and service duration as a firefighter

	PR	CI	β	SE	p
Service duration (month) as a main role :					
Rescuer	1.005	1.002 ~ 1.007	0.0046	0.0013	0.0006
Paramedic	1.001	0.998 ~ 1.005	0.0013	0.0018	0.4797
Driver	0.999	0.997 ~ 1.000	-0.0014	0.0009	0.0893
Suppressor	0.999	0.997 ~ 1.000	-0.0010	0.0010	0.2330
Office worker	0.999	0.997 ~ 1.001	-0.0009	0.0011	0.4269
Ref [a)] (N=1231)	1.000				
Age (year)	1.077	1.063~1.091	0.0741	0.0066	< 0.0001

PR, Prevalence ratio; CI, Confidence interval (95%).
[a)] Reference group is the KNINEP with no service duration as a firefighter.

Percentile distribution of HTLs

The distributions of age and years of service for the firefighters and the two general populations are presented at the top of Table 5-4. For firefighters, age and years of service were highly correlated ($\gamma = 0.93$, $p < 0.001$). Table 5-4 shows a comparison of firefighters' median and 90th percentile HTLs ($n = 912$) with those of KONP ($n = 1130$) and KNINEP ($n = 1231$) by age and frequency. The table consists of 60 cells comparing the HTLs of the three groups. The cells with italic letters indicate that the KONP threshold was worse than that of the firefighters. The cells with bold letters indicate that the KNINEP population was worse than the firefighters at that age and frequency. The HTLs of firefighters were worse than those of the KONP group in 88.3% (53/60) of the 60 comparisons and worse than those of the KNINEP group in 66.7% (40/60) of the comparisons. Compared with KONP, firefighters' HTLs were significantly higher at most test frequencies, but not at low frequencies (0.5, 1 kHz), across most age groups; the exception was the older age group (50–59). Firefighters' HTLs were worse than those of KNINEP in the younger age groups (24–30, 31–40, 41–45 years), but they were not different in the older age groups (45–50, 51–59).

To clarify the comparison, the data in the table are illustrated using a median audiogram (Fig. 5-1 A–E.). Figure 5-1 shows the median and 95% confidence intervals for the firefighters' HTLs, stratified by age and audiometric test frequency, compared with the median thresholds of KONP and KNINEP.

Table 5-4. The percentile distribution of HTLs* firefighter, KONP (n=1130) and KNINEP (n=1231)

Age range		**24~30**			**31~40**			**41~45**			**46~50**			**51~60**		
Group		**FF**	**KO**	**KN**	**FF**	**KO**	**KN**	**FF**	**KO**	**KN**	**FF**	**KO**	**KN**	**FF**	**KO**	**KN**
Number		54	226	160	262	348	374	213	160	162	187	153	170	197	243	365
Age (Mean ± SD)		29±2	27±2	27±2	36±3	36±3	36±3	43±1	43±1	43±1	48±2	48±1	48±1	54±2	55±3	55±3
Years of service as a FF		3±2	-	-	8±5	-	-	16±3	-	-	21±3	-	-	26±4	-	-
Frequency 500 Hz	**P50**	10	9	7.5	7.5	*11* [a)]	**10** [b)]	10	*10.5*	10	10	13	10	10	*15*	**12.5**
	P90	20	16	15	17.5	*18*	**20**	17.5	*20.5*	20	20	22	**22.5**	20	*23*	**27.5**
Frequency 1000 Hz	**P50**	7.5	6.5	2.5	7.5	*8*	5	10	9	7.5	10	11	7.5	10	*13*	10
	P90	20	13	10	20	13	15	20	15	17.5	20	18	17.5	20	20	**27.5**
Frequency 2000 Hz	**P50**	7.5	5	2.5	7.5	6	5	10	7	7.5	10	9	10	12.5	12	**15**
	P90	20	12	12.5	20	14	17.5	22.5	13	17.5	22.5	17	**26.3**	27.5	21	**32.3**
Frequency 3000 Hz [c)]	**P50**	7.5	5	2.5	7.5	5	7.5	15	9	12.5	15	11	13.8	15	17	**22.5**
	P90	25	14	11.3	32.5	14	22.5	37.5	18	**45**	35	23	**40**	42.5	29	**52.5**
Frequency 4000 Hz	**P50**	10	6	5	12.5	7	12.5	20	12	20	20	16	**22.5**	22.5	22	**32.5**
	P90	37.5	16	17.5	47.5	17	37.5	62.5	22	57.5	52.5	29	**56.3**	55	36	**65**
Frequency 6000 Hz	**P50**	17.5	9	12.5	20	10	17.5	30	14	22.5	27.5	19	**32.5**	30	25	**40**
	P90	40	18	26.3	57.5	20	42.5	65	28	65	62.5	33	62.5	65	40	**72.5**

SD, standard deviation; HTL, hearing threshold levels : averaging of bilateral ear dB HL; FF, Firefighter; KO, KONP; KN, KNINEP; P50, 50 percentile; P90, 90 percentile [a)] Italic font mean KONP's HTLs were worse than firefighters' [b)] bold font mean KNINEP's HTLs were worse than firefighters'. [c)] 677 of 1130 have their HTLs at 3000 kHz.

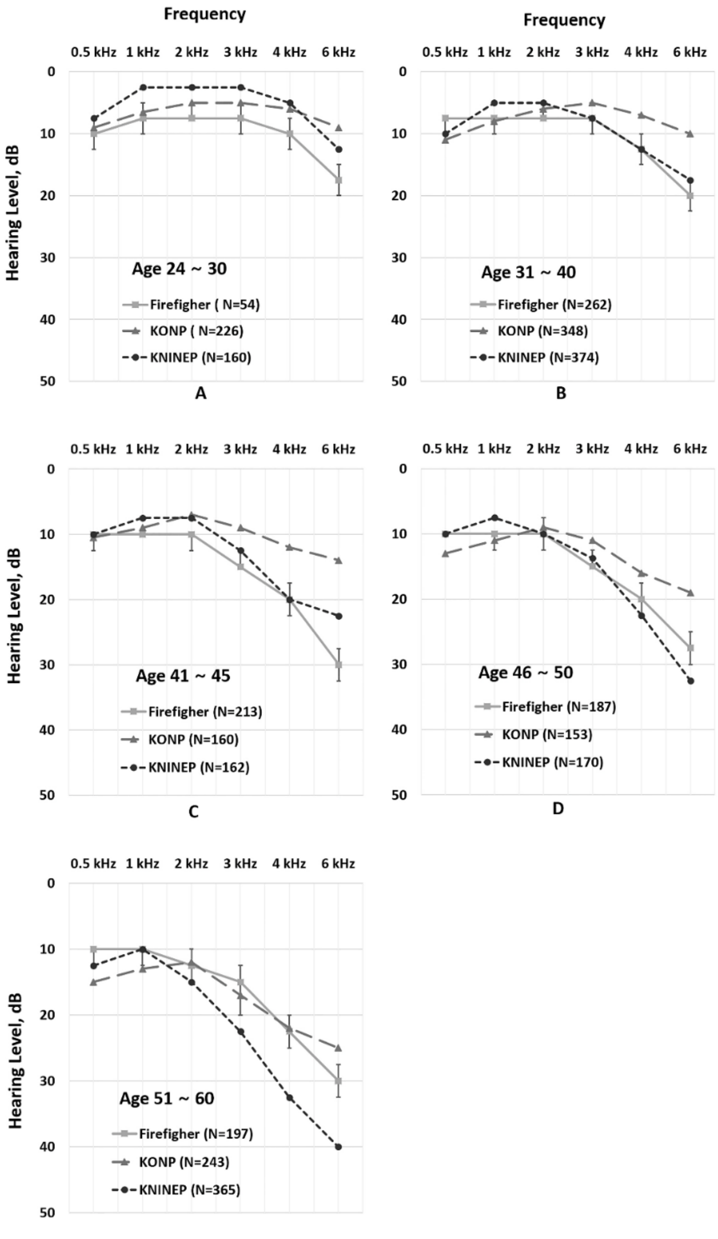

Figure 5-1. Median HTLs (dB HL) by age group for firefighters, KONP and KNINEP. Firefighters shown as squares, KONP as triangles and KNINEP as circles. The 95 percentile upper and lower confidence intervals of firefighters' median HTLs were represented by the vertical bars.

5.4. Discussion

The results of the age-adjusted analysis of hearing loss prevalence among male firefighters and general male populations showed that the prevalence of hearing loss was higher among firefighters than in an otologically screened general population (KONP) and similar to that of an unscreened general population (KNINEP). Rescuers' HTLs were significantly worse than those of the two (screened and unscreened) general populations.

In this study, firefighters' hearing level was compared with data obtained from a general representative Korean population instead of simply comparing their acuity with data from International Standards Organization (ISO1999) or ANSI S3.44.[83 99] This is the first reported study in Asia that assessed firefighters' hearing acuity comparing those of screened and unscreened general population.

Hearing problems in firefighters have been a subject of interest mainly in the UK and North America. Previous related studies can be classified into two major types according to design: 1) cross-sectional studies and 2) longitudinal studies in a cohort of firefighters.

First, cross-sectional studies are more common than longitudinal ones and can provide prevalences, prevalence rate ratios, and prevalence odds ratios of hearing loss in firefighters. The prevalence and prevalence ratio in this study were consistent with firefighters' known risks for audiometric abnormalities, which were more pronounced than in previous studies. Hong et al[100] recently reported that 40.7% of 425 American firefighters had hearing loss, defined as PTA46 of 25 dB or greater in the worse ear. Using the same index (worse ear PTA46 $\geq$ 25 dB), the prevalence in this study was 54.5%. Kales et al[74] reported high-frequency hearing loss (average two ears PTA345 $\geq$ 25 dB) and broad frequency hearing loss (average two ears PTA5124 $\geq$ 25 dB) of 14.4% and 11.7%, respectively. Applying the same definitions used in Kales et al.'s study, the present study found hearing loss of 28.2% at PTA345 and, 21.5% at PTA5124, much higher rates than those reported by Kales et al. The results for prevalence ratios for firefighters versus screened general population from the ISO1999 Annex A[83] in Kales et al[74] were 2.9 for high-frequency hearing loss and 2.9 for broad-frequency hearing loss. In contrast, our study using their definitions yielded values of 4.5 and 2.6, respectively. The difference in the prevalence ratio at high frequencies was very large, and may be attributable to differences in working conditions.

Some critics of comparative studies with screened populations (ISO1999 Annex A) have argued that the effects of occupational noise exposure may be overestimated because highly screened populations generally include more people of relatively higher socioeconomic status (SES) and fewer people having possible risk factors of hearing loss, such as cigarette smoking and diabetes.[91 98 101 102] However, it seems that overestimation related to smoking or SES was small in this study. The social status of firefighters in Korea has been rising gradually. According to the latest survey,[103] firefighters had a college graduation rate of 62.7%, significantly higher than that of KONP (39.8%). The smoking rate among firefighters was also much lower than that among KONP (37.6% vs. 58.8%). Additionally, about 80% of the KONP subjects lived in the capital city (Seoul), where environmental noise, such as traffic noise, is high. This may account for the difference between KONP and the data in ISO1999 Annex A. The median HTLs for the 30-year-old age group at high frequencies (3, 4, and 6 kHz) were 5, 7, and 10 dB in KONP and 2, 2, and 3 dB in ISO1999 Annex A, respectively; the values for those in their 50s were 17, 22, and 25 dB in KONP and 12, 16, and 18 dB in ISO1999 Annex A, respectively.[83]

Clark and Bohl[91] argued that it was inappropriate to attribute differences in hearing between firefighters and a screened general population to occupational noise exposure because the firefighters were not screened. These authors conducted a cross-sectional study comparing Fort Worth, TX, firefighters with unscreened general population from the International Standard Organization (ISO1999 Annex B).[83] They constructed a table showing 72 HTL comparisons between the two populations, representing three percentile levels, six frequencies, and four age groups. In 43.1% of all comparisons, firefighters' HTLs were worse than those of the ISO1999 Annex B, which is not much lower than the 66.7% of comparisons between firefighters and KNINEP found in this study. Indeed, the differences were primarily at younger ages (younger than 45), although it was common that firefighters' hearing levels were better than those of the screened population at high frequencies (3, 4, and 6 kHz) in older age groups (older than 45).

Younger firefighters' hearing levels were obviously worse than those of members of the control groups. There are a number of possible explanations for this. First, some occupational noise-exposed individuals were likely not excluded from KNINEP. Occupational groups that might have experienced high noise exposure, such as agricultural workers, forestry and fishery workers (6.8%), plant and machine operators (19.3%), and routine and repetitive physical workers (5.7%), were included; by an age-adjusted Cochran–Mantel–Haenszel test, their prevalence was significantly higher than that of other types of workers in KNHANES 2011 (PR = 1.09, CI: 1.01–1.18). Our criterion specifying "loud noise emitted from machine or generator for at least 3 months" may have been too narrow to screen for occupational noise exposure. Second, the response rate for KNINEP was relatively low, so the prevalence in KNINEP may not be truly representative of the unscreened general population. The KNHANES 2011 included audiometric examinations on the full sample of subjects aged 12–97 years, with a response rate of 59.5% (6302 people tested), which might have resulted in oversampling of relatively unhealthy, low-income persons. The proportion of low-income subjects included in KNINEP was 45.5%, whereas most firefighters have mid-level incomes. The higher current smoking rate of KNINEP subjects compared with firefighters in general (42.9% vs. 38%) might also have been a source of bias, as smoking has been reported to be significantly associated with an increased risk of high-frequency hearing loss.[102] Third, there may be some problems with the audiometric tests in KNHANES. The audiometric data in KNHANES 2011 were the third since the audiometer and audio booth were changed in 2009. Hearing threshold data prior to the 2009 survey are not available. However, audiometric testing had been conducted in mobile examination centres, i.e., two trailers linked together for use at each health examination site. The guidelines for the survey had no information about ambient noise levels in the room or any detailed guidance to avoid TTS. HTLs of KNINEP may be overestimated due to lack of compliance with the guideline.

Fourth, there may be unique characteristics of Korean firefighters, such as occupational mobility, with or without job mobility (promotion within fire departments). About 20% of firefighters quit their job within 5 years after appointment,[104] and 1.4% of firefighters retire early every year.[105] Firefighters are usually promoted to supervisory roles when they reach their 50s. Supervisory firefighters usually work only in the daytime, instead of alternating 24-h shifts, so their period of occupational noise exposure decreases. It has been reported that firefighters with supervisory roles had significantly lower noise exposure than did those in non-supervisory roles, who were almost always younger firefighters.[80] Fifth, a learning effect, i.e., an artificial improvement in hearing level, is one possible reason for these findings, as firefighters are expected to have a medical examination once a year, including an audiometric test. Although this audiometric test is not used for any hearing conservation programs (HCPs), it is a requirement. Finally, there may have been some increase in noise-exposure levels over time. The number of dispatches has increased fivefold over the past decade, whereas the number of firefighters has increased only 1.5 fold over the same period.[85]

Thus, several possible explanations as to why hearing acuity was worse in the younger firefighters than in the age matched general population (KNINEP) can be suggested. However, given that firefighters must also pass a rigorous physical examination to qualify for duty, including hearing loss of less than 40 dB, the findings are not readily explained. In a cross-sectional study, it is difficult to avoid confounding bias (disparity in health status between the groups) and selection bias (e.g., healthy worker effect (HWE)), which are also limitations of this study. The only way to control for such bias would be to establish a baseline hearing threshold level and risk factor distributions for the firefighters and for the general population.[106 107]

To our knowledge, three longitudinal studies have evaluated firefighters' hearing over time. Tubbs showed that Hamilton, OH, firefighters' mean hearing level at 4 kHz declined by 3 dB (from 21 dB HL to 24 dB HL) over 6 years.[79] Clark and Bohl reported that, despite deterioration by 4.2 dB at the same frequency over 7 years, the hearing of Phoenix, AZ, firefighters did not decline, considering the role of presbycusis Appendix F1 of OSHA standard 1910.95.[91 108]

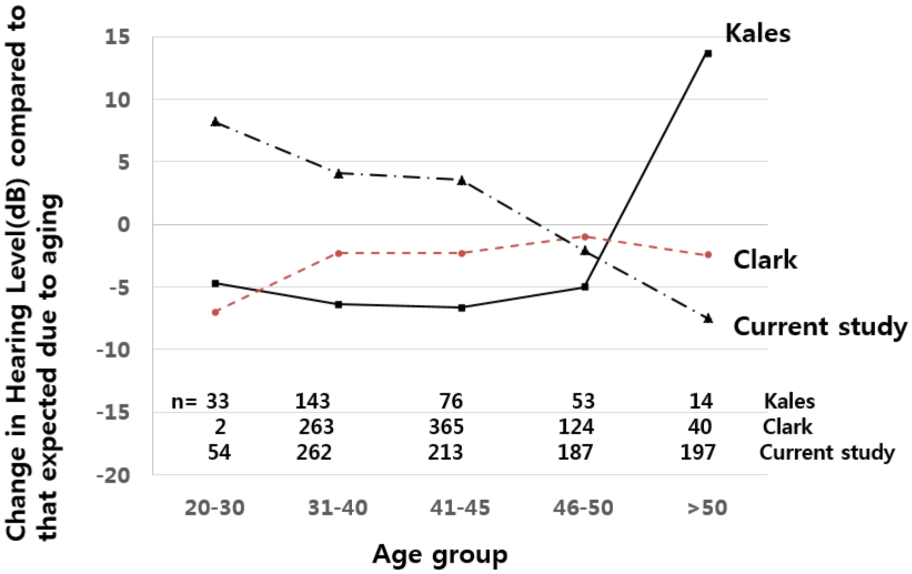

Figure 5-2. The differences between the firefighters' hearing thresholds (averaging the median thresholds at 3, 4 and 6 kHz) and those predicted for persons of the same age groups from unscreened population from Kales' and current study. Dashed lines were from Clark and Bohl's longitudinal data, which was obtained by subtracting presbycusis correction value (Table F-1) of OSHA 1910.95 to interval between firefighter's first annual test and seventh annual test. This figure was cited from reference 91 (Clark and Bohl, 2005), and data from current study were added on that.

Their results are consistent with our findings for firefighters in their mid-40s and 50s. Figure 5-2 is from Clark and Bohl’s paper, and our data have been added to the figure. Clark and Bohl’s data are longitudinal, and those from our study and from Kales et al. are cross sectional. Positive values in longitudinal study indicate the progression of hearing loss during the measurement interval exceeded that expected due to age alone (presbycusis correction value of OSHA

1910.95). In cross sectional studies, the positive value mean that firefighters' hearing thresholds is worse than those of the same age groups from unscreened population. The results for firefighters older than 45 years of age are similar in Clark and Bohl’s study. However, in contrast to both of those studies, the average HTLs of the younger age groups (24–30, 31–40, 41–45) in the current study were worse than expected considering those of the control group (KNINEP). In recent years, related longitudinal research has been conducted in the early stages of firefighters’ careers in the UK. Ide[75] reported that the hearing acuity of firefighters over a short period (mean 4.1 years) was reduced by about 30 dB (from 24.7 to 54.1 dB) as the mean of left ear values averaged over 1, 2, 3, 4, and 6 kHz, which is more than 6 dB deterioration, on average, at each frequency. Those results are in good agreement with our study, which showed that the grand average HTL for firefighters in their 20s (mean 3 years of career) was higher than the unscreened general population by 33.6 dB (66.3 vs. 32.7 dB; $p < 0.001$). Ide[75] suggested that much of the reduction in hearing acuity in the early stages of firefighters’ careers is due to the substantial amount of time spent in training with high noise exposure. An earlier cross sectional study conducted by Reischl et al[72] also estimated that major hearing-level deterioration could occur during the first 3 years of fire service. Ide suggested that the evolution of firefighting techniques and accompanying increase in rescue training may be a cause of increased noise exposure, which is supported to some extent by our noise-exposure assessment.[75]

The higher prevalence among rescuers than general populations is consistent with results of recent noise exposure studies in Korea. In our separate study on noise assessment (not published), rescuers were exposed to the highest mean level of noise ($L_{ep,d}$=84.6 dBA), followed by the driver (83.3 dBA) and suppressor (79.5 dBA) (p=0.04). Ahn et al[103] reported that noise levels in and out of rescue truck cab (Leq24h=72.1 dBA in cab, Lmax=102.1 out of cab) were the highest than any other vehicles in fire department.

Briefly, this cross sectional study showed some association between firefighters' experiences and hearing loss. However, causality cannot be established due to the limitation of cross sectional study. To establish a causal connection between occupational noise and hearing loss among firefighters, a well-designed longitudinal study considering the other risk factors mentioned above is needed.

There are some other limitations beyond those described above. Military service information was not included in this study, which may also be a cause of hearing loss prior to current occupation. However, this effect is unlikely to be large because South Korea has compulsory military conscription for all males.

5.5. Conclusions

The hearing thresholds of younger firefighters and rescuers were worse than expected by normal aging alone. NIHL is irreversible and hearing acuity is one of the most important sense to firefighters' safety. Therefore, to prevent firefighters from hearing loss, hearing conservation program is required. Future research should include longitudinal studies to consider variable risk factors such as military service, smoking, diabetes, etc.

Chapter 6.

Summary and conclusions

Occupational noise exposure of underserved occupations and their nonoccupational activities were assessed in this study. Construction workers, firefighters, musicians, service workers, office workers, housewives, and students were selected as underserved occupations.

The construction workers were exposed to excessive occupational noise, and they are at serious risk of NIHL. The construction trades were a useful noise exposure metric.

Noise exposure of underserved occupations, including Korean traditional music apprentices, firefighters, office workers, housewives, and students, was evaluated by continuous monitoring (24 hours/7 days). Our results show that a large portion of office workers, housewives, and students as well as Korean traditional music apprentices and firefighters are exposed to noise levels greater than the WHO recommended limit. The nonoccupational noise exposure level was over the recommended limit, which means that nonoccupational noise exposure may not be negligible.

Most of the noise exposure (82.3%) for firefighters occurred while checking equipment and responding to fire or emergency calls. A task-specific noise assessment provides valuable information for controlling noise, particularly in jobs characterized by high variability and intermittency, including firefighting and construction work.

Firefighter HTLs were compared between a screened and unscreened population, and the HTLs revealed that the firefighters had worse hearing than the members of the screened population, but were not different from those of the unscreened population. The hearing levels of younger firefighters and rescuers were worse than expected by normal aging alone.

In summary, underserved occupations, including construction workers, Korean traditional music apprentices, and firefighters, are at risk for NIHL. The hearing levels of younger firefighters and rescuers were worse than expected due to normal aging alone. These data indicate the need for a comprehensive assessment and noise reduction efforts in these occupational groups. The general assumption that housewives, students, and office workers are exposed to negligible noise may be incorrect. Nonoccupational noise exposure should be considered when assessing NIHL.

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난청은 인류의 10 대 질환 중 하나이며 최근 관련 연구에서는 그 중 소음성 난청이 약 16%를 차지한다고 보고했다. 소음성 난청은 초기에 자각하기 어렵고 직업성질환이 많아 보고가 잘 이루어지지 않기 때문에 실제 유병율은 이보다 더 높을 것으로 예상된다. 도시화와 여가생활 증가로 일반환경 중 소음노출도 증가하였는데 비직업 소음노출이 소음성 난청 위험성평가에서 제외되고 있는 것도 과소평가의 한 원인으로 본다. 최근 유럽연합이 소음성 난청 예방을 위한 법률(2003/10/EC)을 개정•시행한 것은 이러한 문제점을 개선하기 위한 노력의 일환이다. 유럽연합은 이 법에서 음악 및 연예산업을 포함한 모든 업종에 대하여 소음노출평가 실시를 명문화하였고 소음노출기준을 획기적으로 낮추었다. 이 연구의 목적은 소음에 노출되고 있지만 제대로 평가되지 않았던 관리 취약 직업군(underserved occupation)의 직업 및 비직업

소음노출을 시간활동별로 정밀하게 평가하는 것이다. 이 연구에서는 관리 취약 직업군으로 건설노동자, 음악 연주자, 소방공무원, 서비스노동자, 사무직노동자, 주부, 학생 등을 꼽았다. 건설노동자나 음악연주자는 소음노출수준이 높지만 지금까지 노출평가가 거의 시행되지 않았고, 소방공무원, 서비스노동자 등도 도시지역의 대표적인 소음노출 직업이지만 노출평가는 없었다. 사무직, 주부, 학생 등은 일반적으로 소음에 노출되지 않는 직업군으로 분류되었고 따라서 소음성 난청에 걸리지 않는 것으로 보았다. 이 연구에서는 이러한 가정이 사실인지를 파악하고자 하였다. 관련하여 작업환경 소음노출기준은 비직업 활동 중 소음노출은 무시할 만한 것으로 전제하고 제정되었는데 여러 직업군들의 비직업적 소음노출평가를 통해 이에 대한 검증도 시도했다. 한편 조사대상 직업 중 소방공무원은 소음노출과 소음성 난청과의 인과관계가 아직 잘 밝혀지지 않았으므로 직무활동별 실시간 소음노출평가 및 청력 표준인구집단과의 비교(단면조사)를 통해 청력손실의 직업 연관성을 조사하였다.

· 아파트 건설노동자 직종별 작업환경 소음노출평가

경기도 일대 53 개 아파트 건축현장에서 10 개 직종 건설노동자 139 명에 대하여 작업환경 개인소음노출을 측정한 결과 소음노출수준(L_{MOEL})은 평균 87.8±4.3 dBA으로 소음성 난청 발생 위험수준인 85 dBA를 초과하였다. 직종별로 평균 소음노출수준이 유의하게 달랐는데 할석공이 가장 높은 평균 93.2±2.6 dBA에 노출되었고 철공 88.4±0.7 dBA, 견출공 88.3±2.7 dBA, 석공 87.7±1.9 dBA, 항타공 85.6±1.7 dBA, 형틀목공 84.9 ± 2.4 dBA, 내장목공 83.5 ± 2.1 dBA, 기타 81.4 ± 2.2 dBA 등의 순으로 나타났다. 조사대상 건설노동자들 중 상당수가 소음성 난청에 걸릴 위험이 있고 건설직종별 평균소음노출(Trade Mean) 을 통한 평가방법은 소음 및 청력관리 우선순위 직종을 선별하는데 적절한 방법임을 알 수 있었다.

· 관리 취약 직업군의 24 시간/7 일간 실시간 소음노출평가

서울시에 거주하고 있는 관리 취약직업군 총 47 명을 24 시간 7 일 동안 연속측정한 총소음노출수준은 평균 $L_{eq\ 24hr,w}$=75±7 dBA이고 국악연주자가 89±7 dBA로 가장 높은 소음에 노출되었고 중장비 기사 77±4 dBA, 소방공무원 76±4 dBA, 서비스 노동자 76±5 dBA, 사무직 노동자 75±7 dBA, 산업위생전문가 71±1 dBA,

대학생 및 대학원생 71±5 dBA, 주부 71±4 dBA 등으로 나타났다. 모든 직업군의 평균 소음수준이 세계보건기구 권고기준인 $L_{eq\ 24hr}$=70 dBA를 초과하였다. 사무직, 주부, 학생 등 일반적으로 비소음노출군으로 분류되는 직업군의 63% 가 $L_{eq\ 24hr}$=70 dBA 이상의 소음에 노출되었다. 이 연구에서는 단시간 연속시료채취 방법과 시간별 활동기록(TAD)을 병행하였으므로 직장뿐만 아니라 비직업 국소환경에서의 소음노출을 평가할 수 있었는데, 전체 대상자 47 명의 비직업적 소음노출을 표준화한 소음노출수준($L_{eq\ 24hr}$)은 71 dBA로 세계보건기구 권고기준을 넘었다. 이는 직업적 소음노출만이 아니라 비직업적 소음노출도 소음성 난청에 영향을 줄 수 있다는 것을 말한다. 비직업적 소음노출은 장소별로는 기타실내와 실외에서 각각 장소별 주중 평균 소음노출수준($L_{eq\ ME,w}$)이 78±7 dBA로 가장 높았고 교통수단 이용시 76±4 dBA, 집에서 63±5 dBA 등의 순이었다. 활동별로는 기타실내와 실외의 레저, 쇼핑, 교통수단을 기다리는 동안에 높았는데 이에 대한 소음관리의 필요성을 시사한다.

· 소방공무원의 직무활동에 따른 실시간 소음노출평가

소방공무원은 연기 등으로 시야방해가 많아 청력이 중요한 직무를 수행하므로 이들에게 청력보호와 소음 관리의 필요성은 매우 크다. 관리 취약직업군 중 소방공무원의 직업적 소음노출은 변이가 크고 작업의 특성상 측정이 어려워 지금까지 평가가 제대로 이루어지지 않았다. 이 연구에서는 소방공무원의 소음노출을 보직 별로 전 작업시간 및 각 직무활동 별로 나누어 실시간 평가하였다. 전 작업시간 소음노출은 보직 별로 보면 구조대의 소음노출이 가장 높았고 ($L_{ep,d}$ = 85±6 dBA), 운전요원(83±3 dBA), 진압대(79.5±4 dBA) 등의 순이었고 직무활동 별로는 출동 및 장비점검 작업이 시간비중은 각각 11.2%, 5.3%였지만 소음노출량 비율은 각각 45.6%, 36.7%로 노출량 대부분을 차지하였다. 특히 장비점검 활동은 매우 짧은 시간 동안 고소음에 노출되는 작업으로 우선 소음개선 대상임을 확인했다.

· 소방공무원과 일반 인구집단의 청력 역치 비교 (단면 조사)

서울에 있는 4 개 소방서 남성 소방공무원 912 명의 청력을 고소음에 전혀 노출되지 않고 귀 질환이 없는 건강한 우리나라 성인 남성 1130 명 (KONP) 및 국민건강영양조사시 청력데이타

중 고소음에 노출되지 않은 일반 성인 남성 1250 명 (KNINEP)의 청력과 단면 역학조사 방법으로 연령을 보정하여 비교하였다. 소방공무원은 KONP 보다 유의하게 청력 이상자가 많았고 KNINEP와는 다르지 않았고 45 세 이하의 젊은 연령군만을 보았을 때는 소방공무원이 두 비교집단에 비해 모두 청력손실자가 유의하게 높았다. 단면조사의 한계를 극복하기 위해서 앞으로 소방공무원을 대상으로 청력보존프로그램 수립·시행과 같은 장기적인 청력추적조사가 필요하다.

요컨대, 건설노동자, 국악연주자, 소방공무원 등은 소음성 난청 등 소음노출에 의한 건강영향 위험이 있으며 앞으로 제조업뿐만 아니라 이들에 대한 소음노출평가 및 청력검진도 필요하다. 소음성 난청은 단면조사 보다는 장기적 추적관찰 조사가 인과관계를 밝힐 수 있으므로 앞으로 관계당국은 청력보존프로그램 등의 제도를 관리 취약 직업군에도 적용하는 것이 바람직하다.

한편 지금까지 관련 연구는 비직업적 소음노출은 무시할 만한 것으로 보았으나 이 연구에서는 청력에 건강영향을 줄 수 있는 수준인 것으로 나타났다. 따라서 앞으로 사업장뿐만 아니라

다중이용시설, 교통수단 등에서 일반시민의 소음노출을 줄이기 위한 관리대책도 마련되어야 할 것이다.

주요어 : 소음, 소음노출평가, 소음성 난청, 관리 취약 직업군, 청력 역치, 24 시간, 비직업

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