The Risk of Occupational Injury Increased According to Severity of Noise Exposure After Controlling for Occupational Environment Status in Korea

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Abstract

Objectives: The aim of this study was to examine the relationship between noise exposure and risk of occupational injury. Materials and Methods: Korean National Health and Nutrition Examination Survey was used for the current study. Self-report questionnaires were used to investigate occupational injury and exposure to noise, chemicals, and machines and equipments. Results: In separate analyses for occupation and occupational hazard, the proportion of occupational injuries increased according to severity of noise exposure (all P < 0.05). Compared to the non-exposure group, the respective odds ratio (95% confidence intervals) for occupational injury was 1.39 (1.07–1.80) and 1.67 (1.13–2.46) in the mild and severe noise exposure groups, after controlling for age, gender, sleep hours, work schedule (shift work), and exposure status to hazardous chemicals and hazardous machines and equipments. Conclusions: The current study highlights the association between noise exposure and risk of occupational injury. Furthermore, risk of occupational injury increased according to severity of noise exposure.

Keywords: Injury, noise, occupational injury

INTRODUCTION

Noise-induced stress, both physical and psychological, is an important public health concern worldwide.[1] Most of all, excessive noise exposure is a major cause of hearing loss; almost 500 million people are at a risk of occurrence of noise-induced hearing loss.[2] Furthermore, noise exposure increases such a risk for developing various diseases including cardiovascular disease, as well as psychological disorders.[3-5] Some reports have suggested that noise exposure in occupational settings is additionally linked to occupational injury.[6,7]

High noise exposure attenuates the effects of warning signals during work,[7] an association that remains significant after controlling for hearing defect status of workers.[6] Noise-induced non-auditory stress, such as fatigue or sleeplessness, is also one among the possible explanations for the association between noise exposure and occupational injury.[8] These stresses increase unsafe behaviour and human error, which are linked to occupational injury. Thus, noise-induced stress and its attenuation effects on warning signals can exacerbate the risk of injury in unsafe environments by increasing unsafe behaviour among workers. Nevertheless, despite the biological plausibility of the association between noise exposure and risk for occupational injury, epidemiological investigations on this matter have been infrequent.

Previously, we reported dose–response relationship between noise exposure and occupational injuries.[9] However, that was not an individual level analysis but a factory level analysis. Hence, that article did not control individual factors such as age, gender, hours of sleep, occupation and work schedules. Additionally, previous articles have...
no information about co-exposure risks such as hazardous machines and equipments while noise exposure often co-occurs with hazardous machines and equipments including motor vehicles, drilling machine, etc. There was a possibility that any hazardous machine that makes noise, not noise itself, shall likely increase the risk of an occupational injury. Thus, an in-depth analysis is necessary to elucidate the association between noise exposure and risk of occupational injury.

Ultimately, this study sought to examine the relationship between noise exposure and risk of occupational injury among workers after controlling for individual characteristics as well as exposure to hazardous chemicals and hazardous machines and equipments.

**Materials and Methods**

**Fourth Korean National Health and Nutrition Examination Survey (KNHANES) and ethics statement**

Data from the 4th KNHANES were used for analyses in this study. Participation in the 4th KNHANES was voluntary and participants provided written informed consent for their participation. Participant records were anonymised prior to analysis. This survey was approved by the Institutional Review Board (IRB) of the Korea Centers for Disease Control and Prevention (KCDC) (IRB: 2007-02-CON-04-P; 2008-04EXP-01-C; 2009-01CON-03-2C).

The KCDC conducted the 4th KNHANES from 2007 to 2009. Households were randomly selected for participation by conducting stratified multistage probability sampling based on geographical areas of the Korean population. A total of 600 geographical sampling units were used in the 4th KNHANES, and a total of 13,800 households were enrolled for data collection. The response rate was 78.4%.

**Occupational injury**

The 4th KNHANES included a questionnaire assessing any injury during the past year (past 12 months), which was broken down into sub-questionnaires regarding activity at the time of injury. There were nine options for activity at the time of injury: (1) working at a job, (2) learning activity for school, (3) physical exercise, (4) leisure, (5) normal household activity, (6) social meeting, and (7) other. In the current study, we examined only the results of the ‘working at a job’ sub-questionnaire, which used as the results for occupational injury. Other injuries were defined as non-occupational and, therefore, excluded from our analyses.

**Assessment of occupation and exposure to hazards**

Current occupational status is broken into nine major occupational categories on the 4th KNHANES, which correspond to the Korean Standard Classification of Occupation. We re-organised these classifications into three occupational groups: non-manual workers (e.g. ‘managers, senior officials, professionals’, ‘clerks’, ‘skilled traders’, and ‘sales and customer service’ workers); agriculture, fishery and forestry (AFF) workers; and manual workers (e.g. those working in ‘crafts and related trades, processing’, ‘plant and machine operators’, and ‘elementary workers’). Military personnel were excluded.

Assessments of exposure for during past 12 months to occupational hazards such as noise, hazardous chemicals, and hazardous machines and equipments were also obtained from self-report questionnaires. For noise exposure, a question present in the questionnaire was ‘Are you exposed to noise loud enough that you would raise your voices to keep a conversation during work?’ For the question on exposure history, the answer key consisted of three options: never exposed, exposure without severe problems and exposure with severe problems. These three categories were defined as non-exposure, mild exposure and severe exposure. We re-organised these three categories into two (non-exposure vs. exposure) for hazardous chemicals and hazardous machines and equipment, but retained them for noise exposure.

Participants’ work schedules, categorised into day work and shift work, were also derived from the self-report questionnaire. Only day time work was categorised into day work, day-to-night work, night-to-day work or night work were categorised into shift work. Hours of sleep in current study was categorised into 5 or less hour vs. 5 h more.

**Study population for data analyses**

Of the 10,027 participants who completed the questionnaires related to occupational injury and exposure assessments, 722 (7.2%) participants experienced injury during the past 12 months. Of the 722 participants who experienced injury, 380 (52.6%) participants experienced injury which did not relate to occupational activity, and 342 (47.4%) participants endured an occupational injury within the past 12 months. We excluded 380 participants who experienced injury that did not relate to any occupational activity. Thus, data of 9647 participants were used for data analysis, of which 342 (3.6%) participants endured an occupational injury within the past 12 months.

**Statistical analysis**

Chi-squared tests and t-tests were used to compare differences between occupational injury and no injury groups. All P values for trend were obtained using Cochran–Armitage trend tests. The odds ratios (ORs) and 95% confidence intervals (95% CIs) for occupational injury were calculated using logistic regression model. Multivariate logistic regression model was adjusted for age, gender, hours of sleep, occupation, work schedule and occupational hazard exposure (chemicals/machines and equipment). After that the goodness of fit statistics was conducted on fully adjusted logistic regression model, and
the model fitting was correct ($P > 0.05$). Two-tailed $P$-values less than 0.05 were considered statistically significant.

RESULTS

Demographic and occupational characteristics

Number of cases according to nature of occupational injuries was 137 by car accident, 53 by blunt trauma, 52 by slip down, 32 by fall down, 16 by amputation, 9 by laceration, and 41 by others [Table 1]. The number of body parts affected by occupational injuries was 106 on arm, 80 on leg, 74 on back, 56 in neck, 29 on face, 22 on chest, 5 on abdomen and 10 on others (data was not shown in table).

The occupational injury group was older than was the no injury group ($48.2 \pm 14.1$ vs. $46.1 \pm 14.3$, $P = 0.007$). The proportion of 5 or less sleep hour in occupational injury group was higher than that in no injury group ($17.8\%$ vs. $13.3\%$, $P = 0.017$).

Occupational injuries significantly differed by occupation – the proportion of manual workers in the occupational injury group was greater than that in the no injury group ($43.1\%$ vs. $30.5\%$, $P < 0.001$).

The proportions of mild and severe noise exposure among occupational injury participants were greater than those among no injury participants ($34.8\%$ vs. $26.1\%$, $11.7\%$ vs. $6.2\%$, $P < 0.001$, respectively). The proportions of hazardous chemical exposure and hazardous machine and equipment exposure among occupational injury participants were greater than that among no injury participants ($33.0\%$ vs. $22.0\%$, $40.6\%$ vs. $25.5\%$, $P < 0.001$, respectively).

The association between noise exposure and other occupational characteristics

The proportion of manual workers increased according to the severity of noise exposure (23.7, 43.8, and 54.2\% in non-exposure, mild exposure, and severe exposure groups, respectively, $P$ for trend $< 0.001$). Proportions of hazardous chemical and hazardous machines and equipment exposures also increased according to the severity of noise exposure ($P$ for trend $< 0.001$). Furthermore, the proportion of participants who had been exposed to hazardous machines and equipment increased with noise exposure severity ($P$ for trend $< 0.001$).

Proportion (%) of exposure to hazardous chemicals, or heavy machines and equipments according to occupation

As shown in Table 2, the proportion of hazardous chemicals exposure and that of heavy machines and equipments was greatest in AFF workers ($75.4\%$ for hazard chemistry exposure, $42.1\%$ for heavy machine and equipment, respectively).

| Table 1: Anthropometric and occupational characteristics of study population |
|-----------------------------------------------|------------------|------------------|
| Age                                           | Occupational injury ($n = 342, 3.6\%$) | Non-injury ($n = 9305, 96.5\%$) | $P$ value |
| Gender                                         | 48.2 ± 14.1       | 46.1 ± 14.3       | 0.007    |
| Male                                           | 243 (71.0)        | 4959 (53.3)       | <.001    |
| Female                                         | 99 (29.0)         | 4346 (46.7)       |          |
| Sleep hours                                    | 61 (17.8)         | 1242 (13.3)       |          |
| ≤5 h                                          | 281 (82.2)        | 8063 (86.7)       |          |
| >5 h                                          |                  |                  |          |
| Occupation                                     |                  |                  |          |
| Non-manual                                     | 122 (36.0)        | 4924 (53.2)       | <.001    |
| Agriculture, fishery and forest                | 71 (20.9)         | 1509 (16.3)       |          |
| Manual                                         | 146 (43.1)        | 2822 (30.5)       |          |
| Working character                              | 287 (84.4)        | 7603 (81.9)       | 0.243    |
| Day time worker                                | 53 (15.6)         | 1676 (18.1)       |          |
| Shift worker                                   |                  |                  |          |
| Occupational hazard                            |                  |                  |          |
| Hazard chemistry                               | 229 (67.0)        | 7262 (78.0)       | <.001    |
| Exposure                                       | 113 (33.0)        | 2043 (22.0)       |          |
| Hazard machine, equipment                      | 203 (59.4)        | 6937 (74.6)       | <.001    |
| Exposure                                       | 139 (40.6)        | 2368 (25.5)       |          |
| Noise exposure                                 | 183 (53.5)        | 6302 (67.7)       | <.001    |
| Non-exposure                                   | 119 (34.8)        | 2428 (26.1)       |          |
| Severe exposure                                | 40 (11.7)         | 575 (6.2)         |          |
Proportion (%) of occupational injuries by occupation and exposure characteristics

In separate analyses by occupation [Figure 1], the proportion of occupational injury increased according to the severity of noise exposure. For non-manual workers, the proportions of occupational injury were 2.1, 3.2, and 3.5% in the non-exposure, mild exposure, and severe exposure groups, respectively (P for trend = 0.026). The proportions of occupational injury increased according to noise exposure severity among manual and AFF workers (P for trend for manual worker, P for trend < 0.001 for AFF worker). The proportions of occupational injury also increased according to noise exposure severity in a separate analysis by hazardous chemical exposure (P for trend = 0.002 in no exposed worker, <0.001 in exposed workers). The proportions of occupational injury also increased according to noise exposure severity in a separate analysis by hazardous machines and equipment exposures (P for trend 0.010 in exposed worker, 0.004 in no exposed worker, Figure 1).

Odds ratio for occupational injury by occupation and hazard exposures after adjusting for age and gender

Compared to non-manual workers, AFF workers and manual workers had 1.83 (95% CI 1.29–2.61) and 1.88 (1.46–2.43) times greater odds of occupational injury, respectively, after adjusting for age, gender [Figure 2]. Of particularly interest was that, the risk of occupational injury increased according to the severity of noise exposure (P for trend = 0.016). The adjusted ORs (95% CIs) were 1.57 (1.15–1.87) for the mild noise exposure group and 1.84 (1.27–2.66) for the severe noise exposure group when compared to the non-exposure group, after adjusting for age, gender and occupation. The ORs (95% CIs) for occupational injury were 1.52 (1.19–1.93) for the hazardous chemical exposure group and 1.50 (1.18–1.90) for the hazardous machine and equipment exposure group, after adjusting for age, gender and occupation.

Odds ratio for risk of occupational injury by noise exposure: A multivariate logistic regression model

In a multivariate regression analysis after adjusted for age, gender, hours of sleep, occupation, work schedule and occupational hazard exposure (i.e. chemicals, machine and equipment), the ORs (95% CIs) for occupational injury were 1.39 (1.07–1.80) and 1.67 (1.13–2.46) in the mild and severe noise exposure groups, respectively [Table 3].

**DISCUSSION**

Occupational injuries are common globally, and may result in the death or disability of many workers.[14] In the current study, we found a positive relationship between noise exposure and risk of occupational injury. Although, our previous study showed dose–response relationship between noise exposure and risk of occupational injury[9] that study did not control individual and other environmental risk factors due to lack

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**Table 2: The association between noise exposure and other occupational characteristics**

|                         | Non-exposure | Mild exposure | Severe exposure | P value | P for trend |
|-------------------------|--------------|---------------|-----------------|---------|-------------|
| Occupation              |              |               |                 |         |             |
| Non-manual              | 3758 (58.2)  | 1116 (44.0)   | 172 (28.7)      | <.001   | <.001       |
| Agriculture, fishery and forestry | 1168 (18.1)  | 309 (12.2)    | 103 (17.2)      |         |             |
| Manual                  | 1533 (23.7)  | 1110 (43.8)   | 325 (54.2)      |         |             |
| Hazard chemistry exposure |            |               |                 |         |             |
| Non-exposure            | 5238 (80.8)  | 1866 (73.3)   | 387 (62.9)      | <.001   | <.001       |
| Exposure                | 1247 (19.2)  | 681 (26.7)    | 228 (37.1)      |         |             |
| Heavy machine and equipment |          |               |                 | <.001   | <.001       |
| Non-exposure            | 5470 (84.4)  | 1429 (56.0)   | 241 (39.2)      |         |             |
| Exposure                | 1015 (15.7)  | 1118 (44.0)   | 374 (60.8)      |         |             |

P values for trend were measured by Cochran–Armitage trend test.
of information. Hence, we conducted a new investigation using nationally representative data which have individual information. In current study, associations remained significant in a multivariate logistic regression model even adjusting for age, gender, hours of sleep, occupation, shift work and exposure to hazardous conditions (i.e. chemicals/machines and equipment).

According to Heinrich’s\textsuperscript{[15]} domino theory, multiple errors caused by unsafe environments\textsuperscript{[16]} and unsafe behaviours\textsuperscript{[17]} might precede occupational injuries. A systemic review described noise-induced non-auditory effect including biological, subjective and behavioural factors.\textsuperscript{[18]} Subjectively, annoyance, fatigue and lack of concentration are common. Noise exposure may also be related to behavioural effects such as psychiatric symptoms and learning difficulty. Those responses can relate to human error which may be connected occupational injury.\textsuperscript{[18]} Biologically, sleep disturbance is the most well-known health effect of noise exposure.\textsuperscript{[18]} Noise-induced stress during the day also decreases the quality and quantity of sleep.\textsuperscript{[19,20]} Hence, it is plausible that chronic poor sleep quality due to daytime noise exposure can exacerbate job stress\textsuperscript{[21]} and physical exertion,\textsuperscript{[22,23]} yet both of which are linked human errors and subsequently occupational injury. Our findings support that the hypothesis that noise exposure increases risk of occupational injury.

Noise is often generated by large, often hazardous machines and equipments; thus, the effects of noise exposure on occupational injury might be confounded by the presence of such machines and equipments. However, there is little epidemiological evidence for the association between noise exposure and occupational injury.
exposure and risk of injury once hazardous machines and equipments have been controlled for. Specifically, we highlighted the important role of noise exposure on the risk of occupational injury in our multivariate logistic regression: there was a positive relationship between noise exposure and risk of occupational injury after controlling for exposure to hazardous chemicals/machines and equipment.

Almost one third of workers in Europe suffer from noise exposure between 85 and 90 dB. And 30–50% of workers in Asia are exposed to noise above 90 dB, which is loud enough to ‘obscure’ potential warning signals. Noise can increase human error and reduce buffering between co-workers; thus, the risk of occupational injury increases with increasing severity of noise, as was found in our study in the multivariate regression analysis.

Other studies have indicated co-occurring effects of noise exposure and other occupational stressors, including physical stress of fatigue, on job performance. There was also some combined effect between noise exposure and job complexity to risk of occupational injury. The combined exposure of noise and job complexity disrupted the safety work environment and increased the noise annoyance, workload and irritability in post work.

In one epidemiological study, chronic exposure to organic chemicals worsened working performance, which was associated with human error. The proportion of occupational injuries was highest when there was a co-existence of severe noise exposure and occupational exposure to hazardous chemicals, as illustrated in Figure 2. Similarly, the proportion of occupational injury also increased with the co-existence of severe noise and unsafe working conditions (i.e. hazardous chemicals, machines and equipment). Those results supported the evidence that noise exposure can aggravate unsafe behaviour which is linked to fatigue and reducing amount of attention. The co-existence of severe noise and hazardous chemical, machines and equipment means that there are unsafe environment as well as risk of unsafe behaviour. Hence, to prevent occupational injury, urgent policies and strategies for the reduction of noise are exceedingly important in environments with hazardous chemicals or hazardous machines and equipment.

There were several limitations in the current study. First, because of the nature of cross section study design, the causal direction cannot be discussed. Because we used retrospective, self-report questionnaires to assess exposure, we were unable to quantify exposure to noise, chemicals or hazardous machines and equipment. There were also possibilities that patients who already experienced occupational injury felt more serious annoyance from noise exposure at work place. Furthermore, we have no information about whether noise exposure is coincident with the time of the injury event, and noise exposure characteristics including duration of exposure, constant or occasional, etc. In addition, newer machines might be quieter or more safer than older ones.

But we did not have any information of machines’ characteristics. This was the primary limitation of the present study, and careful consideration of that limitation is critical when interpreting our results. However, previous study estimated the accuracy of the question ‘Are you exposed to noise loud enough that you would raise your voices to keep a conversation during work?’ The sensitivity was 68.5%, and specificity was 74.6% to 85 dB noise exposure measured by noise dosimeter. Furthermore, the finding that ORs for occupational injury increased according to severity of noise exposure (P for trend =0.016, Figure 2) and strengthened the evidence for a relationship between noise exposure and risk of occupational injury. Furthermore, the increment trends in occupational injury proportions remained even in separate analyses by occupation and exposure to occupational hazards. Hence, our consistent results provide relatively solid evidence for a relationship between noise exposure and risk of occupational injury. Nevertheless, further research works using comprehensive and quantitative exposure assessments are necessary to further elucidate the relationship between noise exposure and risk of occupational injury. The noise exposure when not at work also could affect the risk of occupational injury, but we have no information regarding total amount of noise exposure. Appropriate personal protective equipment can reduce noise exposure and its related health effect. Unfortunately, we have no information of personal protective equipment such as ear plug use in workplace. Hence, further comprehensive exposure assessment was needed to clarify the relationship between noise exposure and risk of occupational injury. Because all survey questionnaires were undertaken by visiting the participants’ house, and our study was cross sectional design, severe fatal injury patients might not be enrolled in the current study. Hence, there might be an under estimation problem of severe injury cases. We excluded the 380 participants who experienced injury that did not relate to occupational activity. Misclassification could be occurred by participants in current study. But there were no reasons that the direction of misclassification was towards an injury which did not relate to occupational activity. Hence, non-differential misclassification might have occurred, and that error attenuated the association between noise exposure and risk of occupational injury. Another limitation is that, because the 4th KNHANES was not specifically designed to assess occupational injury, we could not account for additional factors that affect risk of occupational injury, such as factory size, systemic regulation and cultural factors within factories. Therefore, careful consideration of our limitations is necessary to further apply or generalise our findings. Despite these limitations, this study demonstrated that risk of occupational injury increased with severity of noise exposure. These relationships remained significant even after controlling for age, gender, occupation, sleep hour, work schedule and occupational hazards. We hope our result brings social concerns of nose exposure and its non-auditory health effect, such as injury, beyond auditory
effect. To prevent an occupational injury, systemic strategies for reducing noise exposure are urgently needed, especially in unsafe workplaces.

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**Conflicts of interest**

There are no conflicts of interest.

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