BIOMEDICAL ENGINEERING | RESEARCH ARTICLE

The relationship between occupational noise exposure and hypertension using nearest age-matching method in South Korea male workers

Min Gi Kim¹ and Yeon-Soon Ahn²

Abstract: There is no consensus as to whether exposure to noise causes HTN. The objective of this study was to investigate the relationships between occupational noise exposure, pre- HyperTensioN (HTN) and HTN. The study subjects consisted of 107,407 workers who underwent annual special medical check-ups for workers from 2000 to 2004. The control group was an annual medical check-up cohort consisting of 152,790 workers examined over the same time period. The 1:1 nearest age matching of the two groups was done and multivariable logistic regressions were used to evaluate the effects of occupational noise on pre-HTN and HTN. The adjusted odds ratio (OR) of pre-HTN (OR 1.29, 95% CI 1.27–1.32) in noise-exposed workers was significantly higher than that in non-noised exposed workers. The adjusted OR of HTN (OR 1.42, 95% CI 1.38–1.45) in noise-exposed workers was significantly higher than that in non-noised exposed workers. According to this study, occupational noise exposure might be related to pre HTN and HTN.

Subjects: Environment & Health; Health & Society; Public Health Policy and Practice

Keywords: Noise; pre-Hypertension; Hypertension

1. Introduction

Noise is a persistent environmental problem (Van Kempen et al., 2002) and is also an important occupational hazard. Hypertension (HTN), a well-known risk factor for cardiovascular disease, is currently the greatest cause of disability-related retirement worldwide (De Souza et al., 2015). Both short-term clinical studies and long-term laboratory studies of animal models have supported the

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PUBLIC INTEREST STATEMENT

There is no consensus as to whether exposure to occupational noise causes pre- hypertension and hypertension. The authors tried to determine whether there was a difference in the prevalence of prehypertension and hypertension by following the blood pressure of two groups of workers (occupational noise exposure group and non-exposed group) for 5 years. The age, which is the most problematic factor for comparing the two groups, was made as close as possible through the 1:1 nearest age matching technique. The results of this study confirmed the relationship between occupational noise exposure and pre-hypertension and hypertension.

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theory that long-term exposure to environmental noise affects the cardiovascular system and causes disease (e.g., HTN, ischemic heart disease, and stroke) and have indicated possible biological mechanisms (Basner et al., 2014). Many epidemiological studies have shown an association between occupational and environmental noise exposure and HTN (Assunta et al., 2015; Chang et al., 2013; T. Chang et al., 2012. Van Kempen et al., 2002). A meta-analysis of 43 occupational community studies showed a significant relative risk of 1.14 for HTN per 5 A-weighted decibels (dBA) increase in occupational noise (Van Kempen et al., 2002). Workers exposed to noise above 80 weight dBA have been reported have a high risk of HTN and elevated blood pressure (BP) (T. Chang et al., 2012). Workers in the sanitary fixtures industry show a higher prevalence of systolic and diastolic hypertension than controls (Assunta et al., 2015). A cohort study of 578 male workers in Taiwan showed that occupational exposure to noise levels of ≥85 dBA was associated with the development of hypertension and that there was a dose-response relationship between noise exposure and the 10-year incidence of HTN (Chang et al., 2013).

However, there is no consensus among researchers as to whether exposure to noise leads to an increase in BP. Other researchers reported no relationship between occupational noise and HTN (Gan & Mannino, 2018; Inoue et al., 2005; Stokholm et al., 2013; Tessier-Sherman et al., 2017; Zamanian et al., 2013). The recent study of 4,548 participants aged 20 to 69 years in the U.S. National Health and Nutrition Examination Survey did not find a consistent association of occupational noise exposure with BP and HTN (Gan & Mannino, 2018). A large population-based 7-year Danish occupational cohort study which included 145,190 workers from 625 companies representing 10 industrial trades and 100 companies found no significant differences in HTN (Stokholm et al., 2013). No significant difference in BP was found between 197 workers in a noisy plant and 169 workers in a relatively quiet plant (Inoue et al., 2005). No significant change was observed in blood pressure (BP) and heart rate after exposure to 85, 95, and 105 dBA in Iranian steel industry workers (Zamanian et al., 2013). No increased risk of incident HTN with exposure to occupational noise was found among specialty metals manufacturing company workers (Tessier-Sherman et al., 2017).

Previous studies about occupational noise exposure and HTN are limited by small sample size, short follow up time, cross-sectional design, and inadequate comparison groups (Assunta et al., 2015; Chang et al., 2013; T. Chang et al., 2012; Inoue et al., 2005; Tessier-Sherman et al., 2017; Zamanian et al., 2013).

The aim of this study was to assess the effect of occupational noise on HTN through case-control study using a retrospective cohort with more subjects than previous studies (Assunta et al., 2015; T. Chang et al., 2012; Inoue et al., 2005; Tessier-Sherman et al., 2017; Zamanian et al., 2013).

Since 1972, most of noise exposed workers in South Korea have been required to undergo an annual specialized medical check-up (ASMC) under the Industrial Health Safety Act (Korean Ministry of Labor(KMOL), 2004). Using this data, the relationship between noise and HTN will be more clearly identified.

2. Study subjects and methods

2.1. Study subjects

The 108,151 South Korean noise-exposed workers who underwent more than one an ASMC for noise and a general health check-up (GHC) from 1 January 2000, to 31 December 2004. In South Korea, workers who were exposed to more than mean-equivalent sound levels of 85 dBA on a time-weighted average based on a 40-hour work week have to underwent the ASMC for noise according to the Guidelines for the Annual Health Examination of Workers (Kim, 2009). Among 108,151 workers, 744 workers (0.69%) with missing data were excluded. The number of final study subjects were 107,407. The control group was composed of 152,790 workers who underwent a GHC more than once from 1 January 2000, to 31 December 2004, but did not undergo ASMC related to noise or other hazard factors (metals, solvents, vibration, pressure, and others) (Figure 1).
ASMC data for exposure to occupational hazards including noise (143 chemicals, 6 dusts, 8 physical agents, and 19 metals) have been electronically stored and monitored since 2000 by the Korea Occupational Safety and Health Agency (KOSHA). The ASMC for Korean workers has been conducted in more than 100 nation-wide medical centers approved by KOSHA.

In South Korea, GHCs are performed on local householders over 20 years old, including those covered by workplace health insurance. For blue-collar workers, GHCs are required annually. The GHC consists of routine medical history inquiries, physical examinations, and laboratory tests. The physical examination includes the measurement of subjects’ height, weight, SBP, and DBP. The laboratory tests include haemoglobin (Hb), total cholesterol (TC), and a simple urine dipstick test. For the purpose of this analysis, we used each group’s median systolic blood pressure (SBP), diastolic blood pressure (DBP), height, and weight; and their mean body mass index (BMI) and TC levels during the same period. BMI was calculated as weight (kg)/height (m²). Hypertension was defined as SBP higher than 140 mmHg or DBP more than 90 mmHg. Proteinuria was diagnosed by a simple urine dipstick test and was defined as the presence of more than 1+ protein on urine dipstick testing more than once during the same time period as the GHC.

3. Statistical methods
We used the t-test and chi-square test to determine the differences between the noise-exposed workers group and the control group (Tables 1 and 2). Nearest age-matching of the groups with ratio 1:1 was done using the “matching it” function in the R package (Randolph et al., 2014). Multivariable linear and logistic regression were used to evaluate the effects of noise on systolic and diastolic BP and hypertension. BMI, TC, Hb, and proteinuria were used as adjusted factors (Table 3–5). All variables except hypertension and proteinuria were used as continuous variables. We used the R studio version 1.1.419 statistical program for all statistical calculations, with significance level set at p < 0.05.

4. Definitions of variables
The BPs of study subjects were measured using an automatic sphygmomanometer or standard mercury sphygmomanometer after the subject had maintained 5 minutes of stable condition while sitting (Korean Ministry of Labor(KMOL), 2004). If SBP was ≥120 mmHg or DBP was ≥80 mmHg in the first examination, re-examination was performed after more than 2 minutes.(Korea Ministry of Employment and Labor, 2019). If SBP was ≥140 mmHg or DBP was ≥90 mmHg in the first examination, a second examination was performed within the year. (Korean Ministry of Labor(KMOL), 2004) The second examination was performed in the same manner as the first (Korea Ministry of Employment and Labor, 2019) HTN was defined as mean DBP of at least 90 mmHg or mean SBP of at least 140 mmHg from 1 January 2000 to 31 December 2004. Pre-
**Table 1. Characteristics after age-matching in noise exposed group and control group workers (n = 107,407)**

|                              | Control     | Noise        | p-value |
|------------------------------|-------------|--------------|---------|
| n(%), or mean±S.D.           | n(%), or mean±S.D. |              |         |
| Age in 2000(year)            | 36.8 ± 9.4  | 36.2 ± 9.8   | 0.00    |
| <20                          | 1,942(46.8) | 2,207(53.2)  | 0.00    |
| 20–29                        | 27,151(47.6)| 29,880(52.4) |         |
| 30–39                        | 44,225(52.4)| 40,156(47.6) |         |
| 40–49                        | 25,026(49.7)| 25,311(50.3) |         |
| 50–59                        | 8,576(48.3) | 9,172(51.7)  |         |
| >60                          | 1,231(46.3) | 1,425(53.7)  |         |
| Body mass index(kg/m²)       | 23.8 ± 3.0  | 23.6 ± 15.4  | 0.00    |
| <18.5                        | 2,453(34.4) | 4,677(65.6)  | 0.00    |
| 18.5–22.9                    | 40,816(43.0)| 54,023(57.0) |         |
| 23–24.9                      | 28,901(52.9)| 25,721(47.1) |         |
| 25–30                        | 33,157(60.7)| 21,446(39.3)|         |
| >30                          | 2,824(2.6)  | 2,284(44.7)  |         |
| Total Cholesterol(mg/dL)     | 191.6 ± 34.4| 180.8 ± 346  | 0.00    |
| <200                         | 67,887(46.1)| 79,320(53.9) |         |
| 200–240                      | 31,574(57.6)| 23,273(42.4) |         |
| >240                         | 8,690(61.0) | 5,558(39.0)  |         |
| Systolic BP(mmHg)            | 124.3 ± 13.1| 124.3 ± 13.6 | 0.72    |
| Diastolic BP(mmHg)           | 78.9 ± 9.2  | 78.3 ± 9.6   | 0.00    |
| Hypertension (%)             |              |              | 0.00    |
| Normal                       | 34,687(51.8)| 32,331(48.2) |         |
| Prehypertension              | 53,568(50.1)| 53,345(49.9) |         |
| Hypertension                 | 19,896(47.0)| 22,475(53.0) |         |

HTN was defined as mean DBP of at least mean 80 mmHg (but below 90 mmHg) or mean SBP of at least 120 mmHg (but below 140 mmHg) during that time. The authors could not consider the use of anti HTN drug in workers to distinguish between the normal and HTN due to lack of data.

TC test was based on fasting for more than 8 hours and TC and BMI (kg/m²) were measured by the guideline of Ministry of Employment and Labor. The mean TC and BMI during that period were used (WHO/IASO/IOTF, 2000). Ages of study subjects were grouped into under 20, 20–29, 30–39, 40–49, 50–59 and 60 years or older. Based on WHO criteria, BMI was classified into underweight (BMI<18.5), normal (18.5≤ BMI≤22.9), overweight (23≤ BMI≤24.9), obesity (25≤ BMI≤29.9), and severe obesity (BMI>30) (WHO/IASO/IOTF, 2000). TC was classified into under 200, 200–240 and 240 or more by the guideline of Ministry of Employment and Labor (Korea Ministry of Employment and Labor, 2019).

5. Results

5.1. Characteristics of the noise-exposed and control group workers after 1:1 nearest age-matching

After 1:1 nearest age-matching, the mean age of the control group in 2000 (36.8 ± 9.4 years) was statistically higher than that of the noise-exposed group (36.2 ± 9.8 years). However, difference in age in 2000(year) between study subjects and controls (36.2 ± 9.8 vs 42.5 ± 12.7) had been
reduced after 1:1 age matching. BMI, TC and DBP in the control group were significantly higher than in the noise-exposed group. SBP in both groups was not statistically different. The incidence of HTN in noise-exposed group (53.0%) was statistically higher than in control group (47.0%) (Table 1).

5.2. The Adjusted odds ratios of prehypertension among noise-exposed workers and control group workers

On multiple logistic regression, the OR of pre-THN in noise exposed group (OR 1.29, 95% CI 1.27–1.32) was statistically significant higher than that of controls. The OR of pre-THN in study subjects whose age in 2000 was 20–29 (OR 1.10, 95% CI 1.02–1.20), 30–39 (OR 1.06, 95% CI 0.97–1.15), 50–59 (OR 1.67, 95% CI 1.54–1.83) and more than 60 years old or more (OR 2.47, 95% CI 2.17–2.60) was statistically significant higher than that of lower than 20 years in age 2000. The OR of pre-THN in study subjects in normal (18.5 ≤ BMI ≤ 22.9), overweight (23 ≤ BMI ≤ 24.9), obesity (25 ≤ BMI ≤ 29.9), and severe obesity (BMI > 30) were statistically significant higher than that of low weight workers (BMI<18.5). The OR of pre-THN in study subjects in whose TC was 200–240 and >240 were statistically significant higher than that of whose TC <200 workers (Table 2).

5.3. The Adjusted odds ratios of hypertension among noise-exposed workers and control group workers

On multiple logistic regression, the OR of HTN in noise exposed group (OR 1.42, 95% CI 1.38–1.45) was statistically significant higher than that of controls. The ORs of HTN in study subjects 20, 20–29, 30–39, 40–49, 50–59 and 60 years or older in age 2000 were statistically significant higher than that of lower than 20 years in age 2000. The ORs of HTN to BMI and TC in study subjects for control group were similar to that of pre-HTN (Table 3).

Table 2. The Adjusted odds ratios of prehypertension among noise exposed workers and control group workers

| Variable                      | OR    | 95% CI       |
|-------------------------------|-------|--------------|
| Noise exposure                |       |              |
| No                            | 1     |              |
| Yes                           | 1.29  | 1.27 – 1.32* |
| Age in 2000(year)             |       |              |
| <20                           | 1     |              |
| 21–29                         | 1.10  | 1.02–1.20    |
| 30–39                         | 0.94  | 0.87–1.02    |
| 40–49                         | 1.06  | 0.97–1.15    |
| 50–59                         | 1.67  | 1.54–1.83    |
| >60                           | 2.47  | 2.17–2.60    |
| Body Mass Index (kg/m²)       |       |              |
| <18.5                         | 1     |              |
| 18.5–22.9                     | 1.52  | 1.45–1.60    |
| 23–24.9                       | 2.31  | 2.19–2.43    |
| 25–30                         | 3.84  | 3.64–4.05    |
| 30                             | 6.00  | 5.42–6.64    |
| Total cholesterol (mg/dL)     |       |              |
| <200                          | 1     |              |
| 200–240                       | 1.27  | 1.24–1.30    |
| >240                          | 1.61  | 1.53–1.68    |

*p < 0.05.
| Variable                        | OR  | 95% CI          |
|--------------------------------|-----|----------------|
| Noise exposure                 |     |                |
| No                             | 1   |                |
| Yes                            | 1.42| 1.38 – 1.65*   |
| Age in 2000(year)              |     |                |
| <20                            | 1   |                |
| 21–29                          | 1.38| 1.22–1.56      |
| 30–39                          | 1.43| 1.27–1.62      |
| 40–49                          | 2.23| 1.97–2.52      |
| 50–59                          | 4.13| 3.64–4.76      |
| >60                            | 6.54| 5.68–7.53      |
| Body Mass Index (kg/m²)        |     |                |
| <18.5                          | 1   |                |
| 18.5–22.9                      | 1.32| 1.22–1.43      |
| 23–24.9                        | 1.89| 1.75–2.05      |
| 25–30                          | 3.05| 2.82–3.31      |
| >30                            | 5.86| 5.31–6.46      |
| Total cholesterol (mg/dL)      |     |                |
| <200                           | 1   |                |
| 200–240                        | 1.30| 1.27–1.33      |
| >240                           | 1.71| 1.64–1.78      |

*p < 0.05.

6. Discussion

In this large retrospective study, exposure to noise over 85 dBA was positively associated with pre-HTN and HTN in multiple logistic regression. Similar results were observed in recent China studies (Chenet al. 2017; Cayir et al., 2018) and existing South Korea study (SY. Lee et al., 2001). 124,286 young adults (18–40 years) from Project Environmental and LifE style Factors IN metabolic health throughout life course Trajectories (ELEFANT) in China, occupational noise exposure (75 dBA noise exposure for more than 4 hours per day) was associated with increases in BP among participants with elevated SBP, DBP and HTN (Chenet et al. 2017). Noise-exposed subjects had significantly higher levels of SBP and DBP than 1399 control subjects in randomly recruited 1390 China workers (Chenet al. 2017). Noise exposure group was significant explanatory variables for both SBP and DBP, and mean of both SBP and DBP of very high exposure group was higher than that of low exposure group in 852 South Korea manufacturing male workers (SY. Lee et al., 2001).

While occupational noise exposure was associated with SBP, DBP in this study, other studies have shown an association between occupational noise exposure and SBP but not DBP (Chang et al., 2009, Ismaila & Odusote., 2014, JH. Lee et al., 2009; Van Kempen et al., 2002). A meta-analysis of 43 occupational community studies showed a significant relative risk of 1.14 for HTN per 5 dBA increase in occupational noise; while the analysis showed a significant increase in SBP, it showed a non-significant increase in DBP (Van Kempen et al., 2002). The mean SBP in metal manufacturing factory workers who were exposed to a noise level higher than 85 dBA was 3.8 mmHg higher than that of office workers who were exposed to less than 60 dBA; there was no significant increase in DBP (JH. Lee et al., 2009). In a study involving sack manufacturing workers, while there was a significant increase in SBP associated with occupational noise exposure, there was no significant difference in DBP (Ismaila & Odusote., 2014).
Both transient and sustained effects of increasing ambulatory SBP and DBP induced by environmental noise exposure were observed in 60 young adults (Chang et al., 2009). Both transient and sustained effects of occupational noise exposure on increasing SBP were observed in 20 Taiwan automobile workers through 24-h ambulatory monitoring (Chang et al., 2003). Specifically, a difference in SBP during sleep of 16 ± 6 mmHg between high-exposure workers (85 ± 8 dBA) and low-exposure workers (59 ± 4 dBA) and a marginal SBP increase of 1 mmHg per 1-dBA increase in occupational noise exposure at a 60-min lag time during work were observed (Chang et al., 2003). Among the 113 workers in an aircraft manufacturing industrial cohort in China, hypertensive workers exhibited a higher increase in ambulatory SBP caused by occupational noise exposure at work than the normotensive workers on working days (Chang et al., 2015). The greater increase in SBP in the hypertensive group was also found during sleep on non-working days (Chang et al., 2015).

The actual biological mechanism for the increase in BP is not yet completely understood. One possible explanation, the general stress theory, posits that noise affects the autonomic nervous system and the endocrine system, which in turn affects the homeostasis of the human organism (Chang et al., 2003). These persistent changes in endogenous risk factors due to noise-induced dysregulation and disturbed metabolic function promote the development of chronic disorders such as atherosclerosis, hypertension, and ischemic heart diseases over time (Babisch, 2011).

Our study has several limitations. First, using only electronic data collected during GHCS (secondary data), we could not investigate factors known to affect HTN such as lifestyle (smoking, alcohol intake, and physical activity), excessive calorie consumption, family history of HTN, and use of anti-HTN drugs. In addition, the modulator function of sleep in noise-associated cardiovascular effects, described by Babisch (Babisch, 2011), was not addressed as we did not investigate sleep insufficiency in the study subjects.

Second, the authors did not investigate the occupation or job in two groups, the job or occupation may also be different between control and noise-exposed group. This difference may also affect the results. Further occupational studies that include lifestyle factors and job related factors (vibrations or psychical conditions in workplace), family history of HTN, use of anti-HTN drugs, sleep insufficiency are needed.

Finally, recent studies have shown that different levels (intensity and frequency) of noise are associated with HTN (Babisch, 2011; Cayir et al., 2018. Chang et al., 2003) de Souza et al. showed that noise exposure was independently associated with hypertension both at the 75–85 dBA (OR 1.56, 95% CI 1.13–2.17) and at dBA levels of 85 and higher (OR 1.58, 95% CI 1.10–2.26) when using ≤75 dBA as a reference category (De Souza et al., 2015). Chang et al. suggest that occupational noise exposure above 80 dBA for specific periods may be associated with hypertension, and noise frequency at 4000 Hz may have the strongest effect (Chang et al., 2012). A study involving 578 men working in a Taiwan aircraft manufacturing plant showed that occupational exposure to noise levels of 85 dBA and higher was associated with the development of HTN; a significant dose-response relationship was found between noise exposure levels and the 10-year incidence of HTN (Chang et al., 2013). We did not accurately assess occupational noise exposure levels in this study, length of exposition and source of noise. The error in measurements of noise could be bias, or systematic error. In addition, the authors did not investigate the use of earplug and ear muff (type, how to installing, wearing period). Further study of the associations among different levels of intensity, frequency of noise, the use of hearing aid and pre-HTN and HTN in South Korean noise-exposed workers will be needed.

Despite these limitations, our study has several strengths. First is the inclusion of all study subjects’ and controls’ median BP, TC, Hb level, and urine protein measured one to five times. Also, due to the extensiveness of the GHC data, the study sample size was large. Finally, the greatest strength of our study is the use of an age-matching method, which enabled us to compare the SBP, DBP, and HTN in study subjects (occupational noise-exposed workers) and controls (non-occupational noise-exposed workers). Although, there are significant limitations due to lack of data on anti HTN drug, use of hearing
aid and noise exposure, we found a possible relationship between occupational noise exposure ≥ 85 dB(A) and pre-HTN and HTN in South Korean noise-exposed workers. These results may suggest that more enhanced BP monitoring and management of noise-exposed workers may be needed to prevent serious HTN-related health problems. Also, the education and monitoring of use of ear plug and ear muffs in workplace will be needed.

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Approval of the research protocol
This study was reviewed by the Institutional Review Board (IRB) of Dongguk University of Gyeongju Hospital.

Informed consent
N/A (This study met requirements for exemption from IRB review, which included obtaining informed consent from the subjects.)

Animal studies
Not included.

Registry and the Registration No. of the study/trial
110,757-201,602-HR-06-02.

Competing interests
The authors declared no competing Interest.

Author contributions
YSA and MGK conceived the ideas; YSA collected the data; MGK and YSA analysed the data; and MGK led the writing.

Public interest statement
There is no consensus as to whether exposure to occupational noise causes pre-hypertension and hypertension. The authors tried to determine whether there was a difference in the prevalence of pre-hypertension and hypertension by following the blood pressure of two groups of workers (occupational noise exposure group and non-exposed group) for 5 years. The age, which is the most problematic factor for comparing the two groups, was made as close as possible through the 1:1 nearest age matching technique. The results of this study confirmed the relationship between occupational noise exposure and pre-hypertension and hypertension.

Practitioner summary
The authors found a positive relationship between occupational noise exposure ≥ 85 dB(A) and blood pressure and hypertension. These results may suggest that more enhanced blood pressure monitoring in noise-exposed workers may be needed to prevent serious hypertension-related health problems.

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