ORIGINAL ARTICLE
Occupation & Environmental Medicine

JKMS

http://dx.doi.org/10.3346/jkms.2016.31.6.852 • J Korean Med Sci 2016; 31: 852-858

Physical Activity and Blood Lead Concentration in Korea: Study Using the Korea National Health and Nutrition Examination Survey (2008-2013)

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Received: 27 October 2015
Accepted: 7 March 2016

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Physical activity normally has a positive influence on health, however it can be detrimental in the presence of air pollution. Lead, a heavy metal with established adverse health effects, is a major air pollutant. We evaluated the correlation between blood lead concentration and physical activity using data collected from the Korea National Health and Nutrition Examination Survey. Multivariate logistic regression analysis was performed after dividing participants according to whether they were in the top 25% in the distribution of blood lead concentration (i.e., ≥ 2.76 μg/dL), with physical activity level as an independent variable and adjusting for factors such as age, sex, drinking, smoking, body mass index, region, and occupation. The high physical activity group had greater odds of having a blood lead concentration higher than 2.76 μg/dL (odds ratio 1.29, 95% CI 1.11-1.51) compared to the low physical activity group. Furthermore, blood lead concentration is correlated with increasing physical activity.

Keywords: Lead; Physical Exertion; Air Pollution; Korea

INTRODUCTION

Physical inactivity is the most common cause of health problems worldwide (1). According to Lee et al. (2), 6%-10% of deaths by non-communicable disease are caused by physical inactivity. Hallal et al. (3) suggested that 31.1% of people worldwide do not meet the minimum amount of recommended physical activity. As such, numerous approaches have been proposed to increase physical activity, including mass media campaigns, community-based informational approaches, behavioral and social approaches, and environmental and policy approaches (4).

However, physical activity may be detrimental to health with high air pollution conditions (5,6). Because exercise increases the ventilation rate, doing it in highly polluted environments can lead to greater inhalation of air pollutants (7). The consequent inflammatory reaction from the air pollutants becomes a major cause of adverse health effects (8). Accordingly, there is some controversy on the health effects of outdoor physical activity (9,10).

Lead is a major air pollutant (11). Lead is a bluish-grey heavy meal that naturally exists in Earth's crust. It is one of the major non-ferrous metals and has been used for generations for a variety of purposes (12). However, lead was ranked second, after arsenic, in the substance priority list proposed by the Agency for Toxic Substances and Disease Registry in 2013. This list ranks substances according a composite indicator of their frequency, toxicity, and potential for human exposure (13). In general, lead is present in the air, water, soil, and dust (12). The main target of lead toxicity is the nervous system (14). Additionally, lead exposure can increase blood pressure (15) and cause anemia (16), while exposure to high concentrations can cause severe damage to the brain and kidney (17,18) as well as miscarriage in pregnant women and sterility in men (19,20). The International Agency for Research on Cancer has classified lead as a probable carcinogen, with lead itself being classified as group 2B and lead compounds (inorganic) as group 2A (21).

In this study, we aimed to evaluate the correlation between physical activity and lead, which is a commonly used and easily exposed to air pollutant that adversely affects health. Specifically, we looked at blood lead concentration; according to the WHO Regional Office for Europe Air Quality Guidelines, when the atmospheric lead concentration is 0.2 μg/m^3, blood lead concentration can increase up to 12 μg/L (22). We used data from the Korea National Health and Nutrition Examination Survey (KNHANES), a nationally representative survey conducted by the Ministry of Health and Welfare to identify the health and nutritional status of Koreans. Blood lead tests have been conducted annually from 2008 to 2013.

pISSN 1011-8934
eISSN 1598-6357

MATERIALS AND METHODS

Study participants

This study utilized data from the KNHANES between 2008 and 2013. The KNHANES was conducted every 3 years between 1998 and 2005, but it has been conducted annually since 2007 to ensure that the national statistics are as current as possible. Participants are selected via a stratified sampling method using population and housing census data. The KNHANES comprises a health interview, a health examination, and a nutrition survey. Furthermore, in the health examination, a survey on exposure to heavy metals has been conducted annually since 2008.

Among 13,514 persons surveyed with blood lead concentration data, we utilized the data of 11,840, after excluding 1,674 persons without physical activity data.

Variables

Blood lead analyses were performed by the Neodin Medical Institute, a laboratory certified by the Korean Ministry of Health and Welfare. Blood lead was measured using graphite furnace atomic absorption spectrometry with a Zeeman background correction (AAnalystTM 600; Perkin Elmer, Turku, Finland). Commercial reference materials were used for internal quality assurance and control (Lyphochek1 Whole Blood Metals Control; Bio-Rad, Hercules, CA, USA). The coefficients of variation for blood lead were within 10%. External quality assurance and control was ensured by the fact that the Neodin Medical Institute had passed both the German External Quality Assessment Scheme operated by Friedrich-Alexander University and the Quality Assurance Program operated by the Korea Occupational Safety and Health Agency. The institute was also certified by the Ministry of Labor as a designated laboratory for the analysis of specific chemicals, including heavy metals and certain organic chemicals. The limits of detection for blood lead in 2008, 2009, 2010, 2011, 2012, and 2013 were 0.120 μg/dL, 0.142 μg/dL, 0.142 μg/dL, 0.148 μg/dL, 0.172 μg/dL, and 0.173 μg/dL, respectively. None of the participants exhibited values below these detection limits.

Physical activity was measured using the International Physical Activity Questionnaire (IPAQ) (23). Specifically, the IPAQ was used to assess the number of days and average minutes of high-intensity activity, moderate activity, and walking performed longer than 10 minutes during the past 7 days. These raw survey data were then transformed into metabolic equivalent of task minutes per week (MET-min/week), as per the IPAQ scoring protocol; participants were subsequently classified into 3 groups according to their degree of physical activity in the past 7 days, including low (0-599 MET-min/week), moderate (600-2,999 MET-min/week), and high (≥ 3,000 MET-min/week) (24).

Furthermore, study subjects were classified by body mass index (BMI) using the criteria for Asians developed by the Western Pacific Region Office of the World Health Organization (WHO) in 2000. Specifically, subjects were classified as less than 18.5 kg/m^2 (underweight), between 18.5 and 24.9 kg/m^2 (normal weight), and more than 25 kg/m^2 (obese).

The region was classified into 16 areas. According to Annual Report of Air Quality in Korea 2013, region was classified as mean of air lead concentration from 2007 to 2013 less than 0.04 μg/m^3 (Gwangju, Chungcheongnam-do, Jeollanam-do), between 0.04 and 0.05 μg/m^3 (Busan, Daejeon, Seoul, Gyeongsangbuk-do, Gyeongsangnam-do, Chungcheongbuk-do, Daegu, Gangwon-do), and more than 0.05 μg/m^3 (Incheon, Gyeonggi-do, Ulsan, Jeollabuk-do). There is no information about the special self-governing province of Jeju. Jeju island is a famous tourist site for natural landscape in Korea, and it is possible to infer below 0.04 μg/m^3 air lead concentration.

Drinking was classified into "no experience of drinking" and "experience of drinking." Smoking was divided into "never," "less than 5 packs," and "more than 5 packs" during a whole lifetime. Finally, regarding occupation, subjects were divided into "managers and professionals," "clerks," "service and sales workers," "skilled agricultural, forestry, and fishery workers," "craft and equipment workers/machine operation and assembly workers," "elementary occupations," and "unemployed (e.g., housewives, students)."

Data analysis

The KNHANES is a highly complex, stratified, and multistage survey that can represent the Korean population. To ensure that our results were nationally representative, we utilized sampling weights for all analyses.

The blood lead concentration averages were calculated as the geometric means of the various categories mentioned before, including age, sex, region, BMI, physical activity levels, drinking, smoking, and occupation. Simple linear regression analysis was then performed, with region, BMI, physical activity levels, and occupation as independent variables and log-transformed blood lead concentration as the dependent variable. Since the distribution of blood lead concentration was skewed, it was log-transformed before the analysis. Then, we performed a multivariate regression analysis to determine the relation between physical activity levels and log-transformed blood lead concentration; in Model 1, we included age, sex, drinking, smoking, and BMI as covariates, while in Model 2, we included the Model 1 covariates along with region and occupation. Then, we conducted a logistic regression analysis, dividing participants by whether they had a blood lead concentration within the top 25% of the distribution (i.e., ≥ 2.76 μg/dL), with physical activity as the independent variable. In the multivariate logistic regression analysis, we adjusted for age, sex, drinking, smoking, and BMI in Model 1, while in Model 2, we adjusted for region and occupation along with the Model 1 covariates. All statistical analyses were performed using SAS ver. 9.2 (SAS Institute, Cary, NC, USA).

Ethics statement

This study was approved by the institutional review board of the Korea Centers for Disease Control and Prevention (Approval No. 2008-04EXP-01-C, 2009-01CON-03-2C, 2010-02CON-21-C, 2011-02CON-06-C, 2012-01EXP-01-2C, 2013-07CON-03-4C).

RESULTS

The study subjects included 5,933 men (50.1%) and 5,907 women (49.9%) with a mean age of 42.1 (SE 0.20). The geometric mean of blood lead concentration of the total sample was 2.04 μg/dL (95% CI 2.02-2.06). Blood lead concentration according to age was lowest in the below 30 years group, and highest in the 50-59 years group. Men had a blood lead concentration of 2.37 μg/dL, which was higher than that of women. Participants from low (< 0.04 μg/m³) air lead concentration areas had a concentration of 2.15 μg/dL, which was higher than that of participants from high (> 0.05 μg/m³) air lead concentration areas. Participants with BMIs higher than 25 kg/m² exhibited a blood lead concentration of 2.20 μg/dL, which was greater than the concentrations of the other 2 groups. Participants with drinking experience had a concentration of 2.11 μg/dL, which was higher than that of participants without drinking experience. Furthermore, participants who had smoked more than 5 packs in their lifetime had a mean blood lead concentration of 2.54 μg/dL, which was higher than that of participants with no smoking experience and who had smoked less than 5 packs. In terms of occupation, the blood lead concentration was the lowest for unemployed, at 1.86 μg/dL, while it was highest for craft and equipment workers/machine operation and assembly workers, at 2.71 μg/dL. Finally, regarding physical activity, blood lead concentration was lowest among participants with low physical activity (0-599 MET-min/week), at 1.94 μg/dL, and highest among participants with high physical activity (≥ 3,000 MET-min/week), at 2.20 μg/dL (Table 1).

Simple linear regression analysis was performed to investigate relationships of log-transformed blood lead concentration with region, BMI, occupation, and physical activity. Regarding region, using low (< 0.04 μg/m³) air lead concentration areas as the reference, being from high (> 0.05 μg/m³) air lead concentration area was significantly negative related to blood lead concentration (β = -0.055, P = 0.004). For BMI, with a score of less

Table 1. Distribution of blood lead concentrations

Parameters	Blood lead concentration, μg/dL		
	No. of subjects	Geometric mean	95% CI
Age, yr			
< 30	3,371	1.52	1.49-1.54
30-39	2,185	1.99	1.96-2.03
40-49	2,103	2.26	2.21-2.30
50-59	2,118	2.54	2.50-2.59
60 ≤	2,063	2.39	2.33-2.45
Sex			
Male	5,933	2.37	2.33-2.40
Female	5,907	1.75	1.73-1.78
Region (air lead concentration), μg/m³			
< 0.04	1,581	2.15	2.08-2.21
0.04-0.05	6,185	2.02	1.99-2.05
0.05 <	4,074	2.03	1.99-2.07
BMI, kg/m²			
< 18.5	748	1.58	1.52-1.65
18.5-24.9	7,554	2.01	1.98-2.04
25 ≤	3,538	2.20	2.16-2.24
Physical activity level, MET-min/wk			
0-599	2,869	1.94	1.91-1.98
600-2,999	5,635	1.99	1.96-2.02
3,000 ≤	3,336	2.20	2.16-2.24
Drinking			
No	1,807	1.67	1.62-1.71
Yes	10,033	2.11	2.09-2.13
Smoking			
Never	6,970	1.76	1.74-1.79
< 5 packs	367	2.03	1.94-2.13
5 packs ≤	4,503	2.54	2.50-2.57
Occupation			
Managers and professionals	1,532	2.00	1.95-2.05
Clerks	1,060	2.02	1.96-2.08
Service and sales workers	1,473	2.09	2.04-2.14
Skilled agricultural, forestry, and fishery workers	635	2.56	2.46-2.67
Craft and equipment workers/machine operation and assembly workers	1,207	2.71	2.64-2.79
Elementary occupation	932	2.27	2.20-2.34
Unemployed	4,422	1.86	1.83-1.89

CI, confidence interval; BMI, body mass index; MET, metabolic equivalent of task.

Table 2. Regression coefficients of log-transformed blood lead concentrations by simple linear

Parameters	β	SE	P
Region (air lead concentration), μg/m³			
< 0.04	-	-	-
0.04-0.05	-0.060	0.018	0.001
0.05 <	-0.055	0.019	0.004
BMI, kg/m²			
< 18.5	-	-	-
18.5-24.9	0.240	0.022	< 0.001
25 ≤	0.331	0.023	< 0.001
Physical activity level, MET-min/wk			
0-599	-	-	-
600-2,999	0.026	0.012	0.029
3,000 ≤	0.124	0.013	< 0.001
Occupation			
Unemployed	-	-	-
Managers and professionals	0.071	0.015	< 0.001
Clerks	0.080	0.017	< 0.001
Service and sales workers	0.116	0.015	< 0.001
Skilled agricultural, forestry, and fishery workers	0.319	0.023	< 0.001
Craft and equipment workers/machine operation and assembly workers	0.376	0.016	< 0.001
Elementary occupation	0.197	0.018	< 0.001

SE, standard error; BMI, body mass index; MET, metabolic equivalent of task.

 http://dx.doi.org/10.3346/jkms.2016.31.6.852

Table 3. Regression coefficients of log-transformed blood lead concentrations by multiple linear

Physical activity level, MET-min/wk	Model 1*			Model 2†		
	β	SE	*P*	β	SE	*P*
0-599	-	-	-	-	-	-
600-2,999	0.015	0.010	0.129	0.020	0.010	0.051
3,000 ≤	0.070	0.012	< 0.001	0.056	0.012	< 0.001

MET, metabolic equivalent of task; SE, standard error.
*Model 1 adjusted for age, sex, drinking, smoking, and BMI; †Model 2 adjusted for Model 1 variables plus region and occupation.

Table 4. Odds ratios of the logistic regression models relating physical activity levels to high blood lead concentration (≥ 2.76 μg/dL)

Physical activity level, MET-min/wk	Crude		Model 1*		Model 2†	
	OR	95% CI	OR	95% CI	OR	95% CI
0-599	1		1		1	
600-2,999	1.09	0.96-1.23	1.04	0.90-1.19	1.05	0.91-1.21
3,000 ≤	1.62	1.42-1.84	1.37	1.18-1.59	1.29	1.10-1.50

BMI, body mass index; MET, metabolic equivalent of task; CI, confidence interval.
*Model 1 adjusted for age, sex, drinking, smoking, and BMI; †Model 2 adjusted for Model 1 variables plus region and occupation.

Table 5. Regression coefficients of log-transformed blood lead concentrations by multiple linear regression* after stratification by region

Physical activity level, MET-min/wk	Regions with air lead concentration, μg/m^3											
	< 0.04				0.04-0.05				0.05 <			
	No. (%)	β	SE	*P*	No. (%)	β	SE	*P*	No. (%)	β	SE	*P*
0-599	344 (21.8)	-	-	-	1,517 (24.5)	-	-	-	1,008 (24.7)	-	-	-
600-2,999	686 (43.4)	0.045	0.032	0.168	3,008 (48.6)	0.012	0.013	0.380	1,941 (47.6)	0.025	0.018	0.161
3,000 ≤	551 (34.9)	0.083	0.034	0.015	1,660 (26.8)	0.057	0.017	0.001	1,125 (27.6)	0.044	0.020	0.030

MET, metabolic equivalent of task; SE, standard error.
*Adjusted for age, sex, drinking, smoking, BMI, and occupation.

than 18.5 kg/m^2 as the reference, both the 18.5 to 24.9 kg/m^2 and more than 25 kg/m^2 groups had significant positive relationships with blood lead concentration (β = 0.24 and 0.331, respectively, *P* < 0.001). For occupation, all occupations showed positive correlations (with "unemployed" as the reference, *P* < 0.001). The relationships were particularly strong for "skilled agricultural, forestry, and fishery workers" and "craft and equipment workers/machine operation and assembly workers" (β = 0.319 and 0.376, respectively). Regarding physical activity levels, with 0-599 MET-min/week as the reference, significant positive relationships were found for 600-2,999 MET-min/week (β = 0.026, *P* = 0.029) and ≥ 3,000 MET-min/week (β = 0.124, *P* < 0.001; Table 2).

To confirm the relationship between log-transformed blood lead concentration and physical activity, we adjusted for age, sex, drinking, smoking, and BMI (Model 1). Notably, with 0-599 MET-min/week as the reference, only the relationship between blood lead concentration and ≥ 3,000 MET-min/week was significant and positive (β = 0.07, *P* < 0.001). Then, we adjusted for region and occupation (Model 2). Notably, the relationship between blood lead concentration and physical activity of 600-2,999 MET-min/week became significant and positive (β = 0.02, *P* = 0.051); the relationship for ≥ 3,000 MET-min/week remained roughly the same (β = 0.056, *P* < 0.001; Table 3).

We furthermore performed logistic regression analysis to confirm the relation between blood lead concentration and physical activity levels. Participants were divided by whether they had a blood lead concentration of ≥ 2.76 μg/dL. Compared to participants with 0-599 MET-min/week, participants with ≥ 3,000 MET-min/week had significantly greater odds of having high blood lead concentration (crude odds ratio 1.62, 95% CI 1.42-1.84). After adjusting for age, sex, drinking, smoking, and BMI (Model 1), the odds for this group decreased somewhat (adjusted OR 1.37, 95% CI 1.18-1.59), but remained significant. Finally, after adjusting further for region and occupation, the odds decreased again (adjusted OR 1.29 95% CI 1.10-1.50), but remained significant (Table 4).

To confirm regional effect on the relationship between log-transformed blood lead concentration and physical activity, we adjusted for age, sex, drinking, smoking, BMI, and occupation after stratification by region. Notably, with 0-599 MET-min/week as the reference, only the relationship between blood lead concentration and ≥ 3,000 MET-min/week was significant and positive in all region (Table 5).

DISCUSSION

This study aimed to investigate the relationship between blood lead concentration and physical activity level. Our results indicated that participants with high physical activity had significantly greater odds of having high blood lead concentration (≥ 2.76 μg/dL) compared to those with low physical activity.

According to United Nations Environment Program (UNEP), approximately 120,000 tons of lead were released into the atmosphere worldwide in the mid-1990s, of which 89,000 tons originated from the combustion of leaded gasoline. The production of non-ferrous metals and coal combustion are main sources as well (25). Generally, lead is discharged into the atmosphere through high-temperature processes such as combustion of leaded gasoline or coal refinement. In a lead isotope analysis using sediment lead concentration in Korea, Lim et al. (26) reported that the lead consumption rapidly increased from

1950 to 1980, after which it gradually decreased. Furthermore, the use of leaded gasoline was banned in January 1993. Despite this, a UNEP report from 2010 revealed that Korea is ranked third in terms of lead consumption, following the US and China.

Lead in the atmosphere accumulates in the body via breathing. Specifically, industrially emitted lead and lead in the soil are dispersed into the atmosphere through human activities, and breathing introduces the atmospheric lead into the body, thereby increasing the blood lead concentration. This was supported by Richmond-Bryant et al. (27), who reported that atmospheric lead concentration influences blood lead concentration in the general population, and Zahran et al. (28), who found the same specifically among young children. In general, when physical activity increases, so does respiratory rate and tidal volume. Thus, increased physical activity when there is a high concentration of lead in the atmosphere would increase the influx of lead into the body, thereby leading to an increase in blood lead concentration. This was what we found in our study: namely, blood lead concentration was higher among those with higher physical activity, even after adjusting for other factors.

Past studies have noted that blood lead concentration is higher among men than among women, and that it increases with age (29). Bjermo et al. (30) noted that blood lead increases with age cohort, while Ikeda el al. (31) showed that blood cadmium and lead concentrations showed increases with age. In general, with increasing age, there is a greater likelihood of exposure to leaded gasoline or various environmental sources of lead. Regarding the sex differences, women tend to have lower smoking rates and are less likely to hold a job that primarily takes place outdoors, both of which contribute to blood lead concentration (32). Blood lead concentrations have also been associated with smoking (33). Apostoli et al. (34) noted that blood lead concentrations increased with BMI.

Skilled agricultural, forestry, and fishery workers — namely, those whose job activities are mainly outdoors — showed higher blood lead concentrations than did unemployed. Similarly, blood lead concentration was higher among craft and equipment workers/machine operation and assembly workers, whose jobs involve frequent exposure to lead. One might argue that because physical activities in our study included all physical activities (i.e., at home and in the workplace), there is a possibility that occupation was a confounding variable. However, we noted a significant relationship between physical activities and blood lead concentration even after adjusting for occupation.

Exercise generally has a favorable effect on health; specifically, it can help prevent cardiovascular diseases and improve mental health (35,36). However, as our results indicate, exercise may increase the influx of pollutants into the body during certain conditions (9). Furthermore, the half-life of lead in the body is several years. Therefore, the best preventive action is to minimize lead exposure. First, means of minimizing exposure is to consider seasonal variations in atmospheric lead concentration. In the US, the atmospheric concentration of lead is noted to be high in the summer/autumn and low in winter (28). In Japan, it is high from March to May (the “dust season” or *kosa* period), and low from July to August (summer) (37); this is also true in Korea (38). As such, Koreans might minimize outdoor activities in the spring, when the atmospheric lead concentration is high, and maximize them in the summer, when the concentration is low. Furthermore, caution should be taken when performing occupational physical activities when atmospheric lead concentration is high. Second, means of minimizing exposure is to consider regional variation. In Korea, such as Incheon, Gyeonggi-do, Ulsan, Jeollabuk-do area’s air lead concentration level was high. However, in our study there is no difference about the relation between physical activity and blood lead level by the region. It may be explained the percent of high physical activity person in the region. In high lead concentration area, only 27.6% was done high physical activity, however, in low lead concentration area, 34.9% was done.

According to IPAQ, high physical activity (≥ 3,000 MET-min/week) means vigorous-intensity activity on at least 3 days or 7 or more days of any combination of walking, moderate-intensity or vigorous intensity activities. In our study, only high physical activity was significantly correlated with increased blood lead concentration. We recommend to reduce physical activity where air pollution is severe.

There are several limitations of this study. First, the data we utilized did not include information on the location of the physical activity; in other words, we failed to distinguish between indoor and outdoor physical activities. According to the National Survey on Recreational Activities in 2010, however, around 2/3 (68.5%) of sports activities take place out outdoors (39). Second, our study lacked information on differences between indoor and outdoor atmospheric lead concentration. Furthermore, in Korea, since the mean of regional air lead concentration differences are not great, interpretation of the regional effect was limited. Third, this was a cross-sectional study, meaning that we cannot infer any causal relationships. Nevertheless, because we used national data, our study has the benefit of being highly representative. Although lead is a common heavy metal, there have been a few studies on the association of blood lead concentration and physical activity. Through this study, a significant correlation is demonstrated between physical activities and blood lead concentration.

ACKNOWLEDGMENT

This study was conducted using raw data from the KNHANES, which was performed by the Korea Ministry of Health and Welfare.

http://dx.doi.org/10.3346/jkms.2016.31.6.852

DISCLOSURE

The authors have no potential conflicts of interest to disclose.

AUTHOR CONTRIBUTION

Conception and design of the study: Rhie JB, Lee HE. Performing the experiments: Rhie JB, Lee HE. Analysis of data: Rhie JB, Lee HE. Contributed reagents/materials/analysis tools: Rhie JB, Lee HE. Writing: Rhie JB, Lee HE. Final approval: all authors.

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 http://dx.doi.org/10.3346/jkms.2016.31.6.852