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# Occupational exposure to polycyclic aromatic hydrocarbons in Korean adults: evaluation of urinary 1-hydroxypyrene, 2-naphthol, 1-hydroxyphenanthrene, and 2-hydroxyfluorene using Second Korean National Environmental Health Survey data

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**Abbreviations**
BMI: body mass index; CI: confidence interval; IARC: International Agency for Research on Cancer; KECO: Korean Employment Classification of Occupations; KoNEHS:

## ABSTRACT

**Background:** Polycyclic aromatic hydrocarbons (PAHs) are occupational and environmental pollutants generated by the incomplete combustion of organic matter. Exposure to PAHs can occur in various occupations. In this study, we compared PAH exposure levels among occupations based on 4 urinary PAH metabolites in a Korean adult population.
**Methods:** The evaluation of occupational exposure to PAHs was conducted using Second Korean National Environmental Health Survey data. The occupational groups were classified based on skill types. Four urinary PAH metabolites were used to evaluate PAH exposure: 1-hydroxypyrene (1-OHP), 2-naphthol (2-NAP), 1-hydroxyphenanthrene (1-OHPHE), and 2-hydroxyfluorene (2-OHFLU). The fraction exceeding the third quartile of urinary concentration for each PAH metabolite was assessed for each occupational group. Adjusted odds ratios (ORs) for exceeding the third quartile of urinary PAH metabolite concentration were calculated for each occupational group compared to the "business, administrative, clerical, financial, and insurance" group using multiple logistic regression analyses.
**Results:** The "guard and security" (OR: 2.949; 95% confidence interval [CI]: 1.300–6.691), "driving and transportation" (OR: 2.487; 95% CI: 1.418–4.364), "construction and mining" (OR: 2.683; 95% CI: 1.547–4.655), and "agriculture, forestry, and fisheries" (OR: 1.973; 95% CI: 1.220–3.191) groups had significantly higher ORs for 1-OHP compared to the reference group. No group showed significantly higher ORs than the reference group for 2-NAP. The groups with significantly higher ORs for 1-OHPHE than the reference group were "cooking and food service" (OR: 2.073; 95% CI: 1.208–3.556), "driving and transportation" (OR: 1.724; 95% CI: 1.059–2.808), and "printing, wood, and craft manufacturing" (OR: 2.255; 95% CI: 1.022–4.974). The OR for 2-OHFLU was significantly higher in the "printing, wood, and craft manufacturing" group (OR: 3.109; 95% CI: 1.335–7.241) than in the reference group.

**Conclusions:** The types and levels of PAH exposure differed among occupational groups in a Korean adult population.

**Keywords:** Polycyclic aromatic hydrocarbons; Occupations; Occupational exposure; Epidemiology

Korean National Environmental Health Survey; KSCO: Korea Standard Classification of Occupations; LOD: limit of detection; OR: odds ratio; PAH: polycyclic aromatic hydrocarbon; 2-NAP: 2-naphthol; 1-OHP: 1-hydroxypyrene; 1-OHPHE: 1-hydroxyphenanthrene; 2-OHFLU: 2-hydroxyfluorene.

**Competing interests**
The authors declare that they have no competing interests.

**Authors contributions**
Conceptualization: Ryu JY. Data curation: Hong DH, Jo JH, Jung J. Formal analysis: Hong DH, Ryu JY. Investigation: Hong DH, Ryu JY. Methodology: Jo JH, Kim DH. Writing - original draft: Hong DH, Ryu JY. Writing - review & editing: Ryu JY, Kim DH.

## BACKGROUND

Polycyclic aromatic hydrocarbons (PAHs) are chemical pollutants in which 2 or more aromatic rings are bonded.[1] PAHs are produced when organic substances are incompletely combusted, and are carcinogenic, particularly in the lungs, skin, and bladder.[2] Exposure can occur both occupationally and environmentally. The International Agency for Research on Cancer (IARC) has identified PAH occupational exposure levels for some occupations, such as coal-gasification workers, as carcinogenic to humans.[3] Environmental exposure to PAHs can occur via tobacco smoke, food (e.g., grilled meats, fried foods, and grains), ambient air (e.g., indoor heating, cooking, exhaust fumes, and wildfires), water, and soil.[3]

PAH exposure can also occur in occupations other than those identified by the IARC. Several studies have examined PAH exposure in various occupations. The Australian Work Exposures Study reported that the proportion of workers exposed to PAHs was highest in the agriculture sector, followed by public administration and safety, accommodation and food services, and mining.[4] In a Canadian study, by industry, PAH exposure was highest in restaurants, automobile maintenance, gasoline stations, and public administration workers (including firefighters).[5] By occupation, cooks, chefs, automobile mechanics, and firefighters comprise the workers most exposed to PAHs.[5] Koh et al.[6] evaluated PAH occupational exposure in Korea based on urinary 1-hydroxypyrene (1-OHP) levels. Exposure was highest in construction and mining, fisheries, transport, sales, and metal-machinery-part workers.

Although the above studies analyzed PAH exposure in a variety of occupations, they had some limitations. Biological markers were not examined in the Australian and Canadian studies, so they were restricted to evaluating the actual exposure levels of workers to PAHs. In the Korean study, the only PAH biomarker used was 1-OHP; because workers may be exposed to PAHs other than pyrene depending on their occupation, urinary 1-OHP may not accurately reflect PAH exposure. Moreover, previous studies used the standard classification of occupations, which is limited by the fact that skill level is the principle criterion (such that work type and environment can differ within the same occupational group). By supplementing these points, in this study, PAH exposure levels were compared among occupations based on 4 urinary metabolites of PAHs.

## METHODS

### Study participants

The Korean National Environmental Health Survey (KoNEHS), conducted by the National Environmental Research Institute, is a national survey that monitors concentrations of hazardous environmental chemicals and their effects on the Korean population.[7] We used data from the second KoNEHS (2012–2014). The survey covered adults aged > 19 years in 16 regions of Korea; based on data from the 2010 population and housing census, a multi-stage

stratified cluster sampling design was adopted.[7] In total, 6,478 participants were enrolled, distributed evenly among 400 districts.[7] Interviews were conducted and biological samples were collected.[7]

## Classification of occupations

The KoNEHS includes details of participants' current occupation; the data were classified according to the 7th Korean Standard Classification of Occupations (KSCO), We re-coded the data according to the Korean Employment Classification of Occupations 2018 (KECO) and classified occupations based on sub-major (2-digit code) occupational groups of KECO. Because skill level is the principle classification criterion for the major (1-digit code) KSCO occupational groups, tasks and working environment may differ between 2 occupations classified into the same major group. Skill type, which reflects the actual work content, is also considered in the sub-major group in KSCO, but several occupations are classified into different major and sub-major groups despite having the same skill type. In addition, as there are 53 sub-major groups in KSCO, the sample sizes of each are too small to perform meaningful analyses. In contrast, KECO considers skill type before skill level for both the major and sub-major groups, so that occupations, for which the tasks, work environments and chemical exposure at work are similar, are classified into the same major and sub-major groups. Additionally, there are only 35 sub-major groups, such that there are more samples in each group compared with the KSCO.

In this study, among the KECO sub-major groups, those with small sample sizes were combined with other groups likely to have similar occupational environments, to create new larger groups. For example, the group, "business, administrative, clerical, financial, and insurance" was formed by combining "business, administrative and clerical works" with "financial and insurance works." In this manner, the number of occupational groups was reduced from 35 to 26.

## Analysis of urinary PAH metabolite concentrations

We used 4 urinary PAH metabolites to evaluate exposure to PAHs: 1-OHP, 2-naphthol (2-NAP), 1-hydroxyphenanthrene (1-OHPHE), and 2-hydroxyfluorene (2-OHFLU). The KoNEHS analyses of urinary PAH metabolites were conducted as follows.[8] Urine samples were collected into sterile containers, and immediately refrigerated and shielded from light. After transfer to the laboratory, the samples were stored at −20°C until analysis. The urinary PAH metabolites were hydrolyzed with β-glucuronidase/acryl sulfatase, derivatized with bis (trimethylsilyl) trifluoroacetamide, and analyzed by gas chromatography–mass spectrometry. Concentrations were obtained from a calibration curve obtained using the standard addition method. The coefficient of determination ($R^2$) of the calibration curve was > 0.995. The limit of detection (LOD) was 0.015 μg/L for 1-OHP, 0.05 μg/L for 2-NAP, 0.047 μg/L for 1-OHPHE, and 0.04 μg/L for 2-OHFLU. LOD/√2 was used to replace values below the LOD. Urinary PAH metabolite concentrations were adjusted based on urinary creatinine concentrations. Urinary creatinine was measured using a colorimetric method, the ADVIA 1800 instrument (Siemens, Washington, D.C., USA) and a creatinine reagent (Siemens). Participants whose urinary creatinine concentrations did not fall within the reference range (0.3–3.0 g/L) were excluded from the study. The urinary PAH metabolites were classified into 2 groups based on the third quartile of the urinary concentration of each metabolite.


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### Variables

Age, sex, body mass index, smoking status, drinking status, and region were used as covariates. Smoking status was divided into 3 categories (non-smoker, former smoker, and current smoker), and drinking status was divided into 2 categories (drinker and non-drinker). Region was classified into 3 categories (urban, rural, and coastal area).

### Statistical analyses

As the KoNEHS used a multi-stage cluster sampling design, we applied strata, cluster, and sampling weights in our analyses, which were conducted using SPSS software (version 25.0 for Windows; IBM Corp., Armonk, NY, USA).[9] Due to the skewed distributions of all urinary PAH metabolite concentrations, the concentrations were log-transformed.[9] To examine the demographic characteristics of the subjects, we estimated means for continuous variables and percentages for categorical variables. The distributions of demographic variables among occupational groups were examined. Since there are no reference ranges of PAH metabolites to determine high level exposure to PAHs, we used the third quartile of each PAH metabolite's distribution in general population as a cutoff value for high level exposure to PAHs. The fraction exceeding the third quartile of urinary concentration for each PAH metabolite was calculated for each occupational group, and compared among them using odds ratios (ORs) and 95% confidence intervals (CIs) calculated via multiple logistic regression, with adjustment for demographic variables. The "business, administrative, clerical, financial, and insurance" group was used as the reference group because the workers therein were expected to have less occupational exposure to PAH sources, such as coal tars, bitumens, and diesel exhaust. A $p$-value < 0.05 was considered significant.

### Ethics statement

This study was approved by the Institutional Review Board of Inje University Haeundae Paik Hospital (2022-09-018).

## RESULTS

**Table 1** shows the sub-major occupational groups of KECO and the occupational groups of our study. Excluding "housewives" and "students, unemployed, and social service agents" groups, the estimated percentage was highest in the "business, administrative, clerical, financial, and insurance" group (9.2%) and second highest in the "sales" group (6.9%). **Table 2** shows the estimated means and distributions of the demographic variables. The estimated proportion of male and female were similar (49.2% for male and 50.8% for female), and the estimated prevalence of current smokers was 21.5%. Most participants lived in urban areas (93.1%). **Table 3** shows the distribution of demographic characteristics among occupational groups. The proportion of men exceeded 50% in 18 of the 26 groups, and was highest in the "information, communications-related installation, maintenance, and manufacturing" (100%) and "construction and mining" (96.1%) groups. Excluding homemakers, the group with the highest percentage of women was "cooking and food service" (79.9%). The proportion of current smokers was highest in the "police, firefighters, prison officers, and military servicemen" (57.5%), "construction and mining" (56.0%), and "electricity and electronics installation, maintenance, and manufacturing" (50.6%) groups, while the "housewives" (3.5%), "education, law, social welfare, and religious" (10.1%), and "cooking and food service" (11.6%) groups had the lowest percentages of current smokers. The drinking rate was highest in the "chemistry and environmental installation, maintenance, and


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**Table 1.** Occupational groups and their sample sizes

| Sub-major groups (2-digits) in KECO 2018 | | | Occupational groups in this study | | |
|---|---|---|---|---|---|
| Occupational group titles | Estimated percentage (%) | Number[a] | Occupational group titles | Estimated percentage (%) | Number[a] |
| Business, administrative, and clerical works | 7.8 | 405 | Business, administrative, clerical, financial, and insurance | 9.2 | 489 |
| Financial and insurance works | 1.3 | 84 | | | |
| Managers (executive and director) | 2.5 | 144 | Managers | 2.5 | 144 |
| Humanities and social sciences researchers | 0.1 | 4 | Researchers and engineers | 3.8 | 165 |
| Natural and bioscience researchers | 0.1 | 7 | | | |
| Information and communications researchers | 1.3 | 49 | | | |
| Construction and mining researchers | 0.6 | 29 | | | |
| Manufacturing researchers | 1.7 | 76 | | | |
| Education | 3.9 | 206 | Education, law, social welfare, and religious | 5.5 | 309 |
| Law | 0.1 | 8 | | | |
| Social welfare and religious works | 1.5 | 95 | | | |
| Police, firefighters, and prison officers | 0.5 | 19 | Police, firefighters, prison officers, and military servicemen | 0.6 | 23 |
| Military servicemen | 0.1 | 4 | | | |
| Health and medical works | 1.8 | 87 | Health and medical | 1.8 | 87 |
| Art, design, and broadcasting works | 1.0 | 46 | Art, design, broadcasting, sports, and recreation | 1.2 | 56 |
| Sports and recreation works | 0.2 | 10 | | | |
| Beauty works | 0.7 | 46 | Beauty, tour, accommodation, nursing, and parenting | 2.1 | 147 |
| Tour and accommodation works | 0.6 | 31 | | | |
| Nursing and parenting works | 0.7 | 70 | | | |
| Cooking and food service works | 2.4 | 187 | Cooking and food service | 2.4 | 187 |
| Guard and security works | 0.9 | 67 | Guard and security | 0.9 | 67 |
| Cleaning and other service works | 2.1 | 189 | Cleaning and other services | 2.1 | 189 |
| Sales works | 6.9 | 397 | Sales | 6.9 | 397 |
| Driving and transportation works | 4.3 | 236 | Driving and transportation | 4.3 | 236 |
| Construction and mining works | 2.4 | 152 | Construction and mining | 2.4 | 152 |
| Machine installation, maintenance, and manufacturing works | 1.8 | 99 | Machine installation, maintenance, and manufacturing | 1.8 | 99 |
| Metal and material installation, maintenance, and manufacturing works | 0.8 | 44 | Metal and material installation, maintenance, and manufacturing | 0.8 | 44 |
| Electricity and electronics installation, maintenance, and manufacturing works | 2.0 | 83 | Electricity and electronics installation, maintenance, and manufacturing | 2.0 | 83 |
| Information, communications-related installation, maintenance, and manufacturing works | 0.2 | 11 | Information, communications-related installation, maintenance, and manufacturing | 0.2 | 11 |
| Chemistry and environmental installation, maintenance, and manufacturing works | 0.4 | 23 | Chemistry and environmental installation, maintenance, and manufacturing | 0.4 | 23 |
| Textile and apparel manufacturing works | 0.7 | 47 | Textile and apparel manufacturing | 0.7 | 47 |
| Food manufacturing works | 0.6 | 51 | Food manufacturing | 0.6 | 51 |
| Printing, wood, and craft manufacturing works | 0.9 | 46 | Printing, wood, and craft manufacturing | 0.9 | 46 |
| Routine manufacturing works | 0.8 | 53 | Routine manufacturing | 0.8 | 53 |
| Agriculture, forestry, and fisheries | 4.5 | 559 | Agriculture, forestry, and fisheries | 4.5 | 559 |
| Not classified in KECO | 41.7 | 2,814 | Housewives | 24.3 | 1,862 |
| | | | Students, unemployed, and social service agents | 17.4 | 952 |
| Total | | 6,478 | Total | | 6,478 |

KECO: Korean Employment Classification of Occupations.
[a]Unweighted sample size.

manufacturing" group (91.7%). The proportion living in urban areas exceeded 90% in almost all occupations, except for "agriculture, forestry, and fisheries" (57.3%), and "information and communications-related installation, maintenance, and manufacturing" (89.0%).

**Table 4** shows percentages below LODs, estimated means and distributions of urinary PAH metabolites. **Table 5** shows the fractions exceeding the third quartile of urinary concentrations for each PAH metabolite, and the adjusted ORs for each occupational group. The groups with the largest fractions exceeding the third quartile of the 1-OHP level were "construction and mining" (47.8%), "food manufacturing" (41.4%), "guard and security" (41.3%), "driving and transportation" (40.3%), and "agriculture, forestry, and fisheries"


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**Table 2.** Demographics in the Second KoNEHS

| KoNEHS (2012–2014) | Estimated mean ± SE or unweighted sample size (estimated %) |
|---|---|
| Age (years) | 46.3 ± 0.4 |
| Sex | |
| Male | 2,774 (49.2) |
| Female | 3,704 (50.8) |
| BMI (kg/m$^2$) | 24.1 ± 0.1 |
| Smoking | |
| Non-smoker | 4,259 (62.7) |
| Ex-smoker | 1,058 (15.8) |
| Current smoker | 1,161 (21.5) |
| Drinking | |
| No drinking | 2,654 (35.3) |
| Drinking | 3,824 (64.7) |
| Region | |
| Urban | 5,765 (93.1) |
| Rural | 485 (5.8) |
| Coastal | 228 (1.1) |

KoNEHS: Korean National Environmental Health Survey; SE: standard error; BMI: body mass index.

**Table 3.** Distribution of demographic characteristics among occupational groups

| Occupational group | Sex (male)[a] | Age (years) | BMI (kg/m$^2$) | Smoking (current smoker)[a] | Drinking[a] | Region (urban)[a] |
|---|---|---|---|---|---|---|
| Business, administrative, clerical, financial, and insurance | 235 (56.0) | 39.6 ± 0.6 | 24.2 ± 0.2 | 109 (27.0) | 375 (79.7) | 457 (95.6) |
| Managers | 109 (82.0) | 48.4 ± 1.0 | 24.9 ± 0.4 | 43 (32.4) | 109 (79.9) | 127 (93.0) |
| Researchers and engineers | 153 (92.1) | 38.8 ± 0.8 | 25.1 ± 0.3 | 55 (29.2) | 140 (83.4) | 154 (95.9) |
| Education, law, social welfare, and religious | 95 (36.6) | 39.6 ± 0.9 | 23.2 ± 0.3 | 31 (10.1) | 195 (65.3) | 283 (93.3) |
| Police, firefighters, prison officers, and military servicemen | 22 (95.2) | 38.9 ± 2.4 | 24.7 ± 0.6 | 12 (57.5) | 20 (90.4) | 21 (93.1) |
| Health and medical | 26 (33.9) | 36.2 ± 1.4 | 22.8 ± 0.5 | 11 (13.3) | 57 (65.7) | 85 (98.7) |
| Art, design, broadcasting, sports, and recreation | 32 (59.4) | 36.5 ± 1.4 | 24.5 ± 0.7 | 15 (32.2) | 44 (82.8) | 51 (91.5) |
| Beauty, tour, accommodation, nursing, and parenting | 27 (24.3) | 47.0 ± 1.4 | 24.1 ± 0.3 | 16 (15.1) | 76 (50.9) | 134 (95.0) |
| Cooking and food service | 28 (20.1) | 47.3 ± 1.3 | 24.6 ± 0.4 | 22 (11.6) | 114 (65.2) | 167 (92.2) |
| Guard and security | 64 (91.2) | 54.0 ± 3.4 | 23.8 ± 0.4 | 21 (31.9) | 42 (72.6) | 63 (93.4) |
| Cleaning and other services | 58 (31.7) | 57.8 ± 1.5 | 24.7 ± 0.3 | 29 (16.3) | 95 (52.0) | 178 (96.4) |
| Sales | 210 (60.3) | 44.5 ± 0.8 | 24.7 ± 0.2 | 95 (30.1) | 274 (72.5) | 367 (95.5) |
| Driving and transportation | 218 (96.0) | 48.2 ± 0.9 | 25.1 ± 0.3 | 100 (47.4) | 172 (73.6) | 219 (92.6) |
| Construction and mining | 141 (96.1) | 48.9 ± 1.1 | 24.6 ± 0.3 | 69 (56.0) | 114 (80.3) | 134 (93.2) |
| Machine installation, maintenance, and manufacturing | 83 (88.7) | 41.4 ± 1.1 | 23.8 ± 0.4 | 37 (37.3) | 80 (75.8) | 93 (92.9) |
| Metal and material installation, maintenance, and manufacturing | 39 (91.7) | 43.0 ± 1.9 | 24.1 ± 0.5 | 17 (39.7) | 37 (83.5) | 42 (92.2) |
| Electricity and electronics installation, maintenance, and manufacturing | 72 (90.0) | 38.6 ± 1.6 | 24.4 ± 0.6 | 31 (50.6) | 68 (76.0) | 74 (90.3) |
| Information and communications-related installation, maintenance, and manufacturing | 11 (100.0) | 43.6 ± 3.2 | 23.4 ± 0.6 | 5 (44.8) | 8 (79.5) | 10 (89.0) |
| Chemistry and environmental installation, maintenance, and manufacturing | 15 (69.3) | 43.4 ± 2.2 | 25.1 ± 0.4 | 8 (40.0) | 21 (91.7) | 20 (91.3) |
| Textile and apparel manufacturing | 14 (51.1) | 51.1 ± 1.7 | 24.8 ± 0.6 | 9 (32.5) | 26 (68.8) | 44 (97.7) |
| Food manufacturing | 16 (35.3) | 48.1 ± 3.0 | 24.7 ± 0.7 | 6 (14.4) | 37 (79.4) | 42 (91.6) |
| Printing, wood, and craft manufacturing | 35 (82.1) | 47.0 ± 1.5 | 24.2 ± 0.5 | 14 (38.6) | 32 (77.1) | 38 (91.4) |
| Routine manufacturing | 12 (30.6) | 46.2 ± 2.3 | 24.2 ± 0.5 | 8 (17.5) | 34 (65.7) | 49 (91.6) |
| Agriculture, forestry, and fisheries | 310 (58.0) | 61.5 ± 0.9 | 24.6 ± 0.2 | 103 (23.5) | 281 (53.0) | 295 (57.3) |
| Housewives | 4 (0.4) | 52.0 ± 0.5 | 24.0 ± 0.1 | 70 (3.5) | 767 (44.3) | 1,720 (94.8) |
| Students, unemployed, and social service agents | 745 (73.6) | 42.3 ± 1.0 | 23.6 ± 0.2 | 225 (22.9) | 606 (69.9) | 898 (96.6) |
| Total | 2,774 (49.2) | 46.3 ± 0.4 | 24.1 ± 0.1 | 1,161 (21.5) | 3,824 (64.7) | 5,765 (93.1) |

Values are presented as number (estimated %) or mean ± standard error.
BMI: body mass index.
[a]Unweighted sample size.

(40.2%). The adjusted ORs were significantly higher in the "guard and security" (OR: 2.949; 95% CI: 1.300–6.691), "driving and transportation" (OR: 2.487; 95% CI: 1.418–4.364),


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**Table 4.** Estimated means and distributions of urinary polycyclic aromatic hydrocarbon metabolites

| Metabolite | Number[a] | LOD (μg/L) | Percentage below LOD (%) | Estimated GM (95% CI) (μg/g Cr) | Estimated percentile (μg/g Cr) | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | 5th | 25th | 50th | 75th | 95th |
| 1-OHP | 6,418 | 0.015 | 2.8 | 0.1986 (0.1909–0.2067) | 0.0601 | 0.1280 | 0.2009 | 0.3121 | 0.6517 |
| 2-NAP | 6,410 | 0.050 | 1.0 | 3.0728 (2.9276–3.2255) | 0.5429 | 1.3281 | 2.8019 | 7.4000 | 20.6370 |
| 1-OHPHE | 6,413 | 0.047 | 21.0 | 0.1239 (0.1194–0.1286) | 0.0410 | 0.0777 | 0.1214 | 0.1934 | 0.3809 |
| 2-OHFLU | 6,397 | 0.040 | 7.3 | 0.3666 (0.3490–0.3852) | 0.0923 | 0.1883 | 0.3097 | 0.7073 | 2.0524 |

LOD: limit of detection; GM: geometric mean; CI: confidence interval; 1-OHP: 1-hydroxypyrene; 2-NAP: 2-naphthol; 1-OHPHE: 1-hydroxyphenanthrene; 2-OHFLU: 2-hydroxyfluorene.
[a]Unweighted sample size.

"construction and mining" (OR: 2.683; 95% CI: 1.547–4.655), and "agriculture, forestry, and fisheries" (OR: 1.973; 95% CI: 1.220–3.191) groups than the reference group.

The "driving and transportation" group had the largest fraction exceeding the third quartile of urinary 2-NAP concentration (43.0%), followed by the "information, communications-related installation, maintenance, and manufacturing" group (42.1%). No group had significantly higher ORs than the reference group, while the "researchers and engineers" (OR: 0.432; 95% CI: 0.236–0.792), "health and medical" (OR: 0.311; 95% CI: 0.114–0.848), "food manufacturing" (OR: 0.140; 95% CI: 0.027–0.729), and "routine manufacturing" (OR: 0.346; 95% CI: 0.131–0.915) group had significantly lower ORs than the reference group.

The "cooking and food service" group had the highest fraction (39.4%) exceeding the third quartile for 1-OHPHE. The groups with significantly higher ORs were "cooking and food service" (OR: 2.073; 95% CI: 1.208–3.556), "driving and transportation" (OR: 1.724; 95% CI: 1.059–2.808), and "printing, wood, and craft manufacturing" (OR: 2.255; 95% CI: 1.022–4.974). The "chemistry and environmental installation, maintenance, and manufacturing" group had a significantly lower OR (OR: 0.187; 95% CI: 0.042–0.837).

The group with the largest fraction exceeding the third quartile for 2-OHFLU was "construction and mining" (56.6%), followed by the "printing, wood, and craft manufacturing" (50.9%) and "electricity and electronics installation, maintenance, and manufacturing" (49.8%) groups. Workers employed in "printing, wood, and craft manufacturing" had a significantly elevated OR (OR: 3.109; 95% CI: 1.335–7.241) compared to the reference group.

## DISCUSSION

In this study, the fraction exceeding the third quartile of urinary concentration for PAH metabolites differed among occupational groups. Among the groups with significantly higher ORs than the reference group, the "cooking and food service," "driving and transportation," "construction and mining," and "agriculture, forestry, and fisheries" groups were also reported to have high proportions of workers exposed to PAHs in previous studies.[4-6]

The "cooking and food service" group displayed high excess fractions of 1-OHP and 1-OHPHE, with higher ORs in both cases compared to the reference group (especially significant for the latter). Many studies have identified PAH emissions, including phenanthrene and benzo[a]pyrene, from commercial-kitchen exhaust systems.[10-12] In particular, Masuda et al.[13] reported that the proportion of phenanthrene in the PAHs of cooking exhaust gas was much higher than that of urban air and exhaust gas from an

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**Table 5.** Fractions exceeding the third quartiles of urinary concentrations for each polycyclic aromatic hydrocarbon metabolite and adjusted ORs for each occupational group

| Occupational groups | 1-OHP | | | | 2-NAP | | | | 1-OHPHE | | | | 2-OHFLU | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Number[a] | % Q3 (95% CI) | OR[b] | 95% CI for OR | Number[a] | % Q3 (95% CI) | OR[b] | 95% CI for OR | Number[a] | % Q3 (95% CI) | OR[b] | 95% CI for OR | Number[a] | % Q3 (95% CI) | OR[b] | 95% CI for OR |
| Business, administrative, clerical, financial, and insurance | 420 | 20.1 (15.6–25.5) | Ref. | Ref. | 420 | 27.2 (22.2–32.9) | Ref. | Ref. | 421 | 19.6 (15.3–24.8) | Ref. | Ref. | 420 | 30.0 (24.4–36.2) | Ref. | Ref. |
| Managers | 136 | 25.5 (18.2–34.4) | 1.335 | 0.730–2.440 | 136 | 24.2 (16.0–35.0) | 0.679 | 0.313–1.473 | 136 | 23.8 (15.8–34.2) | 1.208 | 0.681–2.144 | 136 | 29.0 (19.6–40.7) | 0.743 | 0.248–2.222 |
| Researchers and engineers | 148 | 18.0 (11.9–26.4) | 1.141 | 0.634–2.052 | 148 | 16.4 (10.8–24.0) | **0.432** | **0.236–0.792** | 148 | 22.4 (15.3–31.6) | 1.551 | 0.915–2.630 | 147 | 26.1 (18.8–35.1) | 0.709 | 0.327–1.540 |
| Education, law, social welfare, and religious | 269 | 19.9 (14.5–26.7) | 1.226 | 0.758–1.982 | 270 | 14.0 (9.7–19.9) | 0.683 | 0.370–1.260 | 269 | 14.0 (8.6–21.9) | 0.733 | 0.389–1.384 | 268 | 12.5 (8.4–18.1) | 0.549 | 0.284–1.064 |
| Police, firefighters, prison officers, and military servicemen | 21 | 17.4 (6.2–40.3) | 0.732 | 0.227–2.357 | 20 | 32.8 (13.1–61.2) | 0.850 | 0.184–3.922 | 21 | 15.3 (4.6–40.3) | 0.717 | 0.181–2.841 | 21 | 45.3 (23.4–69.2) | 0.926 | 0.128–6.716 |
| Health and medical | 77 | 18.8 (9.8–32.9) | 1.048 | 0.394–2.786 | 76 | 9.8 (4.8–18.7) | **0.311** | **0.114–0.848** | 77 | 25.1 (14.5–40.0) | 1.542 | 0.694–3.424 | 77 | 13.1 (7.1–23.1) | 0.367 | 0.104–1.295 |
| Art, design, broadcasting, sports, and recreation | 50 | 31.8 (17.7–50.4) | 2.058 | 0.810–5.229 | 50 | 32.0 (18.8–48.9) | 1.363 | 0.557–3.338 | 50 | 27.6 (14.8–45.5) | 1.657 | 0.671–4.090 | 49 | 26.5 (15.2–42.0) | 0.700 | 0.171–2.863 |
| Beauty, tour, accommodation, nursing, and parenting | 115 | 18.8 (11.5–29.3) | 0.718 | 0.360–1.435 | 115 | 18.8 (11.1–30.1) | 0.610 | 0.312–1.191 | 115 | 22.6 (13.8–34.7) | 0.923 | 0.434–1.963 | 115 | 25.0 (15.0–38.7) | 1.180 | 0.550–2.534 |
| Cooking and food service | 158 | 33.1 (23.9–43.8) | 1.705 | 0.952–3.054 | 157 | 20.2 (12.6–30.7) | 0.861 | 0.434–1.707 | 158 | 39.4 (29.6–50.2) | **2.073** | **1.208–3.556** | 157 | 15.8 (10.0–24.0) | 0.748 | 0.379–1.475 |
| Guard and security | 58 | 41.3 (25.7–58.8) | **2.949** | **1.300–6.691** | 60 | 37.0 (22.4–54.4) | 1.712 | 0.682–4.297 | 58 | 20.4 (9.6–38.2) | 0.889 | 0.369–2.141 | 57 | 35.7 (20.8–53.9) | 1.450 | 0.461–4.559 |
| Cleaning and other services | 144 | 32.4 (23.6–42.7) | 1.362 | 0.816–2.273 | 146 | 24.8 (17.4–34.2) | 0.789 | 0.413–1.508 | 144 | 31.2 (22.2–41.8) | 1.178 | 0.678–2.046 | 144 | 26.4 (17.8–37.3) | 1.135 | 0.534–2.412 |
| Sales | 336 | 26.9 (21.3–33.4) | 1.365 | 0.861–2.165 | 337 | 26.7 (21.4–32.7) | 0.811 | 0.499–1.319 | 336 | 25.9 (20.4–32.4) | 1.299 | 0.868–1.945 | 336 | 31.0 (25.0–37.6) | 0.884 | 0.461–1.694 |
| Driving and transportation | 217 | 40.3 (31.7–49.7) | **2.487** | **1.418–4.364** | 219 | 43.0 (34.8–51.6) | 1.398 | 0.842–2.322 | 217 | 32.3 (24.8–40.9) | **1.724** | **1.059–2.808** | 217 | 47.0 (38.4–55.8) | 1.391 | 0.718–2.693 |
| Construction and mining | 139 | 47.8 (37.1–58.6) | **2.683** | **1.547–4.655** | 139 | 39.7 (29.9–50.5) | 0.724 | 0.368–1.424 | 139 | 34.9 (26.0–44.9) | 1.663 | 0.946–2.924 | 138 | 56.6 (46.1–66.5) | 1.485 | 0.642–3.433 |
| Machine installation, maintenance, and manufacturing | 91 | 23.0 (14.7–34.1) | 1.206 | 0.598–2.430 | 90 | 33.0 (23.0–44.9) | 1.100 | 0.544–2.224 | 91 | 25.2 (16.5–36.4) | 1.501 | 0.822–2.740 | 91 | 31.4 (21.9–42.7) | 0.606 | 0.258–1.422 |

(continued to the next page)

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**Table 5.** (Continued) Fractions exceeding the third quartiles of urinary concentrations for each polycyclic aromatic hydrocarbon metabolite and adjusted ORs for each occupational group

| Occupational groups | 1-OHP | | | | 2-NAP | | | | 1-OHPHE | | | | 2-OHFLU | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Number[a] | % Q3 (95% CI) | OR[b] | 95% CI for OR | Number[a] | % Q3 (95% CI) | OR[b] | 95% CI for OR | Number[a] | % Q3 (95% CI) | OR[b] | 95% CI for OR | Number[a] | % Q3 (95% CI) | OR[b] | 95% CI for OR |
| Metal and material installation, maintenance, and manufacturing | 43 | 25.0 (14.1–40.4) | 1.406 | 0.649–3.044 | 43 | 27.2 (14.7–45.0) | 0.762 | 0.244–2.379 | 43 | 14.1 (6.6–27.5) | 0.689 | 0.290–1.640 | 43 | 37.7 (23.1–55.0) | 1.181 | 0.321–4.348 |
| Electricity and electronics installation, maintenance, and manufacturing | 77 | 33.8 (21.1–49.3) | 1.783 | 0.826–3.849 | 77 | 34.2 (20.6–51.1) | 0.711 | 0.264–1.920 | 77 | 25.1 (14.0–40.8) | 1.312 | 0.647–2.661 | 77 | 49.8 (35.1–64.6) | 1.210 | 0.478–3.064 |
| Information, communications-related installation, maintenance, and manufacturing | 11 | 29.8 (9.7–62.5) | 1.710 | 0.316–9.242 | 11 | 42.1 (15.5–74.2) | 1.647 | 0.095–28.575 | 11 | NA | NA | NA | 11 | 44.8 (17.3–75.9) | 1.409 | 0.572–3.468 |
| Chemistry and environmental installation, maintenance, and manufacturing | 20 | 17.0 (6.2–38.9) | 0.665 | 0.179–2.467 | 20 | 35.4 (15.0–62.9) | 1.074 | 0.369–3.128 | 20 | 5.2 (1.2–19.8) | **0.187** | **0.042–0.837** | 20 | 48.9 (24.9–73.4) | 2.108 | 0.607–7.315 |
| Textile and apparel manufacturing | 41 | 24.5 (11.5–44.9) | 0.921 | 0.366–2.318 | 40 | 36.8 (19.9–57.7) | 1.467 | 0.429–5.013 | 41 | 26.2 (13.0–45.6) | 1.027 | 0.422–2.496 | 40 | 33.4 (16.7–55.6) | 1.233 | 0.284–5.352 |
| Food manufacturing | 43 | 41.4 (22.2–63.7) | 2.702 | 0.939–7.774 | 43 | 5.6 (1.3–21.3) | **0.140** | **0.027–0.729** | 43 | 32.7 (18.1–51.6) | 1.646 | 0.695–3.899 | 43 | 26.3 (10.9–50.9) | 1.482 | 0.374–5.875 |
| Printing, wood, and craft manufacturing | 43 | 30.3 (18.1–45.9) | 1.557 | 0.690–3.514 | 44 | 38.4 (23.3–56.2) | 1.372 | 0.707–2.661 | 43 | 36.8 (22.8–53.5) | **2.255** | **1.022–4.974** | 43 | 50.9 (35.2–66.4) | **3.109** | **1.335–7.241** |
| Routine manufacturing | 48 | 20.7 (10.4–36.8) | 0.833 | 0.354–1.959 | 48 | 13.9 (5.7–30.3) | **0.346** | **0.131–0.915** | 48 | 13.6 (6.4–26.7) | 0.482 | 0.196–1.183 | 48 | 18.1 (7.9–36.1) | 0.467 | 0.196–1.114 |
| Agriculture, forestry, and fisheries | 470 | 40.2 (34.2–46.5) | **1.973** | **1.220–3.191** | 471 | 29.0 (23.6–35.1) | 0.849 | 0.530–1.359 | 470 | 36.3 (30.4–42.6) | 1.382 | 0.905–2.111 | 470 | 32.2 (26.4–38.6) | 1.287 | 0.716–2.313 |
| Housewives | 1,496 | 23.3 (20.5–26.4) | 0.922 | 0.603–1.410 | 1,494 | 18.2 (15.7–20.9) | 0.866 | 0.564–1.330 | 1,496 | 30.1 (27.2–33.2) | 1.153 | 0.794–1.674 | 1,494 | 11.8 (9.5–14.5) | 0.787 | 0.425–1.459 |
| Students, unemployed, and social service agents | 833 | 18.0 (14.4–22.3) | 0.987 | 0.663–1.469 | 836 | 28.6 (24.8–32.8) | 1.429 | 0.924–2.210 | 834 | 17.9 (14.4–22.0) | 0.990 | 0.695–1.409 | 832 | 22.6 (19.0–26.6) | 0.728 | 0.435–1.219 |
| Total | 5,504 | 25.0 (23.1–27.0) | | | 5,510 | 25.0 (23.3–26.8) | | | 5,506 | 25.0 (23.1–27.1) | | | 5,494 | 25.0 (23.1–27.0) | | |

Bold indicates statistically significant results ($p < 0.05$).
1-OHP: 1-hydroxypyrene; 2-NAP: 2-naphthol; 1-OHPHE: 1-hydroxyphenanthrene; 2-OHFLU: 2-hydroxyfluorene; % Q3: fraction exceeding the third quartile; OR: odds ratio; CI: confidence interval; NA: not available.
[a]Unweighted sample size.
[b]Adjusted for age, sex, body mass index, smoking status, drinking status, and region.

incinerator. A Chinese study reported that the sources of PAHs in the air in commercial kitchens were cooking-oil fumes and cooking practice.[14] When cooking oil is heated, PAHs in the oil evaporate into the air, and are pyrolyzed and resynthesized into smaller PAHs.[15] Regarding cooking practice, certain cooking methods (i.e., frying and broiling), high cooking temperatures, and high fat content of foods are associated with more PAH emissions.[14,16] According to Pan et al.,[17] the average benzo[a]pyrene concentrations in kitchens and dining areas in Chinese restaurants were 6.9 and 1.1 ng/m$^3$, respectively, which exceeds the target value of 1 ng/m$^3$ in ambient air set by the EU.[18] Oliveira et al.[19] reported significantly elevated levels of urinary monohydroxyl-PAHs, including 1-OHPHE and 1-OHP, in grill workers during workdays.

Motor vehicles are a major source of PAHs in cities.[20,21] Incomplete combustion by motor vehicle engines, particularly heavy-duty and diesel engines, produces large amounts of PAHs.[22] Several studies have reported that naphthalene, phenanthrene, fluorene, and pyrene are the major PAHs from diesel-engine exhaust,[23-25] which accords with the high excess fractions and ORs for all 4 PAH metabolites in our "driving and transportation" group. In particular, the urinary 1-OHP and 1-OHPHE levels of this group were significantly higher compared to the reference group. The interior of a vehicle can become contaminated with PAHs mainly by infiltration of outside pollutants, mostly from the exhausts of vehicles and, to a lesser degree, home heating exhaust systems and resuspended soil.[26] Several studies reported high benzo[a]pyrene concentrations inside vehicles (> 1 ng/m$^3$), particularly during the winter.[27-29] For example, the 24-hour exposure amount for benzo[a]pyrene among taxi drivers in Genoa, Italy was significantly higher (1.22–1.4 ng/m$^3$) than that of a control group (0.16 ± 0.12 ng/m$^3$).[28] Considering that Korean taxi drivers' average driving time is 10.2 hours per day,[30] significant PAH exposure can be expected in this group. Indeed, some studies showed that urinary 1-OHP levels in taxi and bus drivers were higher than in controls.[31-33]

In this study, the "construction and mining" group exhibited high excess fractions of all 4 PAH metabolites, and urinary 1-OHP levels differed significantly between this group and the reference group. Construction workers, such as roofers and road pavers, can be exposed to PAHs while handling bitumens and coal tar.[34-36] Moreover, construction and mining workers may be exposed to PAHs from exhaust generated by construction and mining machinery.[37-39]

Our "agriculture, forestry, and fisheries" group exhibited high PAH levels. The excess fractions and ORs for 1-OHP, 1-OHPHE, and 2-OHFLU were high in this group; in particular, there was a significant difference in urinary 1-OHP concentrations compared to the reference group. The Australian Work Exposures Study[4] suggested that incinerating agricultural waste and exhaust fumes from agricultural equipment, such as lawn mowers, could lead to PAH exposure among farmers. Furthermore, a variety of PAHs (mainly low molecular weight ones) are released during open burning of agricultural residues; among particulate PAHs, phenanthrene and fluorene were the most common.[40] PAHs generated by open burning of crop residues increase atmospheric PAH concentrations.[41,42] Regarding PAH exposure in fisheries, urinary 1-OHP levels were higher in ship-engine-room workers, especially those with oil-contaminated skin, compared to a control group.[43,44]

In this study, urinary PAH metabolite levels were elevated in the "guard and security" and "printing, wood, and craft manufacturing" groups, neither of which has been well-studied. In particular, the excess fractions and ORs for 1-OHP, 2-NAP, and 2-OHFLU were high in the "guard and security" occupation group; however, we could not find any previous studies on this group. Considering that this group consisted mainly of building concierges (61 of 67


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group members), PAH exposure may have been caused by proximity to vehicle exhausts in building parking lots or on the roadside.[45]

Our "printing, wood, and craft manufacturing" group included various occupations, such as woodworking and printing; as the sample size for each individual occupation was small, false-positives may have arisen. Some studies have shown that ink and wood processing are associated with exposure to PAHs. In one study, PAHs such as benzo[a]pyrene and phenanthrene were detected in newspaper ink; these can penetrate through the skin to cause genotoxicity.[46] During woodworking, various PAHs are generated from incomplete combustion of wood, resulting in exposure among woodworkers.[47,48] Another study showed that concentrations of phenanthrene and fluorene from wood burning were higher compared with other sources, such as plastics and paper.[49] These findings may explain the large excess fractions of all 4 PAH metabolites in this occupation group seen in our study, as well as the significant differences in urinary 1-OHPHE and 2-OHFLU levels compared to the reference group. Therefore, potential PAH exposure should be monitored continuously in these workers.

The excess fraction of 1-OHPHE in our "chemistry and environmental installation, maintenance, and manufacturing" group was low, and was significantly lower compared to the reference group. The 1-OHPHE was analyzed for 20 subjects in this group and the group comprised 3 minor occupational groups (3-digit code): 2 in the petroleum and chemical material processing machine-operator group, 14 in the chemical, rubber, and plastic production machine-operator group, and 4 in the water treatment and recycling machine operator group. The average urinary 1-OHPHE concentrations in these 3 minor groups were 0.1359, 0.1218, and 0.0913 μg/g Cr, respectively. The geometric mean urinary 1-OHPHE level for all participants in this study was 0.1239 μg/g Cr; thus, the concentrations in petroleum and chemical material processing-machine operators exceeded the overall mean. However, due to the small sample sizes, it was difficult to conduct analyses for these minor groups.

The "food manufacturing," "health and medical," "routine manufacturing," "education, law, social welfare, and religious," and "researchers and engineers" groups in this study had the smallest 2-NAP excess fractions; in all of these groups (except "education, law, social welfare, and religious" group), the levels of urinary 2-NAP were significantly lower compared to the reference group. Urinary 2-NAP is a naphthalene metabolite; as naphthalene exists mostly in the gaseous phase, it could be used as an indicator of airborne PAH exposure.[50] Therefore, our results imply that workers in the groups listed above may be less exposed to airborne PAHs than other workers.

Our study analyzed 4 urinary PAH metabolites and showed that types and levels of PAH exposure differed among various occupations. This implies that analyses of various PAH metabolites is needed when evaluating PAH exposure. Furthermore, as we classified occupational groups based on the sub-major groups of KECO, occupations with similar tasks and work environments could be classified into the same groups.

Our study had several limitations. First, in several occupational groups the number of samples was insufficient. Additionally, due to small numbers of samples, some occupations that were expected to have high PAH exposure levels were combined, so could not be evaluated individually (e.g., traffic police and firefighters, which were combined to create the group "police, firefighters, prison officers, and military servicemen"). Second, due to the short half-lives of PAHs, the sampling performed in KoNEHS may not accurately

reflect occupational exposure. Third, the KoNEHS measured only 4 PAH metabolites, and our study could evaluate only exposure to those PAHs. Forth, information related to PAH exposure by general environment or local air condition are lack in KoNEHS data. Although we adjusted for regional classification as a demographic factor in the analyses, it may be too broad to clearly reflect regional differences of PAH exposure by general environment or local atmospheric condition.

## CONCLUSIONS

This study found that the types and levels of PAH exposure differed among occupations in the Korean adult population. Further studies are merited for validation, as well as appropriate protective measures for workers in those occupations.

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