# $PM_{2.5}$ and hospitalizations through the emergency department in people with disabilities: a nationwide case-crossover study in South Korea

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## Summary

**Background** Little is known about the impact of $PM_{2.5}$ on people with disabilities. We aimed to explore the association between $PM_{2.5}$ and hospitalization via the emergency department (ED admission) among people with disabilities, together with the attributable ED admission cases and costs.

**Methods** We applied a time-stratified case-crossover design adjusting ozone, holiday, and temperature using seven years (2015–2021) of claim-based data on ED admissions from the Korean National Health Insurance Database. The analysis included all ED admission cases of beneficiaries with disabilities living in Korea (physical, intellectual, and mental disabilities; brain lesion disorders; blindness or vision loss; deafness or hearing loss; and autism) as well as selected controls without disabilities.

**Findings** There were 900,311 ED admissions among the 3,624,590 people with disabilities. The odds ratios of ED admissions associated with a 10 $\mu g/m^3$ increase in $PM_{2.5}$ were 1.039 (95% CI: 1.036–1.042) in people with disabilities and 1.022 (95% CI: 1.019–1.025) in people without disabilities. Individuals with mental disability, intellectual disability, and brain lesion disorder showed higher risk estimates compared to other disabilities. The risk estimates of ED admissions for cardiovascular and genitourinary diseases were more prominent among people with disabilities than those without disabilities.

**Interpretation** The impacts of $PM_{2.5}$ on ED admissions was generally higher in the population with disabilities than those without disabilities, especially for certain causes of admission. These results could contribute to establishing targeted action plans including early warning system referring different threshold concentrations.

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**Keywords:** $PM_{2.5}$; Time-stratified case-crossover; Emergency department visit; Disability

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**Translation:** For the Chinese translation of the abstract see the Supplementary Materials section.

## Research in context

### Evidence before this study

Short-term fine particles ($PM_{2.5}$) exposure increases the risk of emergency department visits, and several individual-level factors such as sex, age, income status, and health status act as effect modifiers. However, epidemiological studies examining and quantifying the hazardous impacts of $PM_{2.5}$ on people with disabilities are largely scarce, although some literature has suggested them as a high-risk population. We searched papers in Google Scholar and PubMed with the search terms "air pollutant*" or "particulate matter", "disability" or "disable*" or "disorder" or "impairment" or "blindness" or "deafness" or "handicap*", for publications published in English before August 31, 2023. Few studies assessed the impacts of $PM_{2.5}$ on people with disabilities; in particular, potential heterogeneities depending on the types of disabilities have been rarely explored.

### Added value of this study

This study, which included all people with one of seven types of disabilities registered in the National Health Insurance that covers approximately 99% of people residing in South Korea, suggests that $PM_{2.5}$ was associated with a higher risk of admissions through the emergency department in people with disabilities compared to people without disabilities. Higher $PM_{2.5}$ risk estimates and related hospitalization cases and costs were observed among individuals with mental disability, intellectual disability, and brain lesion disorder than those with other disability types or without disabilities. To our knowledge, it is the largest study evaluating the risk estimates of admissions through the emergency department associated with $PM_{2.5}$ in seven types of disabilities, with various causes of admissions.

### Implications of all the available evidence

Our findings highlight the importance of public health policies for people with disabilities related to $PM_{2.5}$ and the necessity of more targeted strategies depending on the types of disabilities.

## Introduction

Numerous studies have reported that ambient fine particulate matter ($PM_{2.5}$) impacts various aspects of human health, including premature death and circulatory, renal, neurological, and respiratory diseases, and mental disorders.[1,2] According to the World Health Organization, exposure to $PM_{2.5}$ was estimated to cause 4.2 million premature deaths worldwide per year in 2019,[3] and global health burden studies reported that deaths attributable to ambient $PM_{2.5}$ were approximately 7–30 times larger than those attributable to ambient ozone.[4] These hazardous impacts have been consistently observed in different countries and populations.[2] Further, previous epidemiological studies revealed that the impacts of $PM_{2.5}$ are higher in certain populations, such as socially marginalized individuals, persons aged 65 years or over, and ethnic/cultural minority populations.[1,5] People with physical-health needs, autism, and specific mental disorders such as schizophrenia also showed a higher sensitivity of air pollutants to cardiovascular morbidities and hospitalization.[6,7]

Globally, around 15% of persons have some form of disability, and the percentage is expected to increase with aging and an increase in chronic diseases.[8] If care providers are accounted for, the number of people associated with disabilities will be even larger. Nevertheless, the impacts of air pollutants on people with disabilities have not been specifically studied, despite plausible reasons for this population to be regarded as a high-risk population. First, they are at higher risk of being socially and materially deprived and experiencing lower accessibility to and availability of healthcare services than their counterparts without disabilities.[9] These forms of social determinants have been considered in other populations in relation to susceptibility to air pollution,[10] and the susceptibility could play certain roles in exacerbating health conditions attributable to $PM_{2.5}$.[6] Second, the population with disabilities has a higher prevalence of chronic diseases,[11] and chronic health conditions contribute to susceptibility to $PM_{2.5}$ exposure.[12] Many studies have highlighted the importance of understanding health impacts for people with disabilities, especially in the context of climate change and air pollution.[13] However, although vulnerability has been broadly investigated for other at-risk populations,[6] few relevant studies have investigated people with disabilities. Moreover, research is even more limited on the impact of air pollutants by types of disability.

Therefore, we performed a nationwide time-stratified case-crossover study to examine the association between short-term $PM_{2.5}$ exposure and hospitalization through the emergency department among people with and without disabilities living in South Korea. This study also addressed the heterogeneous associations by seven types of disabilities and excess admission cases and costs attributable to $PM_{2.5}$.

## Methods

### Data source

We collected the nationwide hospitalization data via the emergency department (ED admission) by cardiovascular, genitourinary, and respiratory diseases, and mental disorders from the National Health Insurance Database (NHID) of the National Health Insurance Service (NHIS) from January 1, 2015 to December 31, 2021 in

South Korea (hereafter referred to as Korea). Theoretically, all people living in Korea are to be registered in the NHIS, and more than 99% of people residing in Korea are activated beneficiaries of the NHIS.[14] The NHIS-NHID includes information on enrollees (including age, sex, disability type, and insurance-based income), district-level residential address, healthcare resource use (hospital visits, diagnoses according to the International Classification of Diseases Tenth Revision (ICD-10), and medications), and associated costs for each claim.[14] Further, as a confounder, the satellite-based daily mean temperatures (°C), relative humidity (%), and precipitation (mm) were collected from the ERA5-Land dataset via the Google Earth Engine.[15]

### Ethical statement

This study was approved by the Institutional Review Board of Seoul National University, Seoul, Korea (IRB No. E2302/004-002).

### Study population

Korea has a national disability registration system that has been in operation since 1988, based on the Welfare of People with Disabilities Act and the registration rate was 94.1% in 2017.[16] The registration process is based on a certificate prescribed by a medical doctor with relevant medical records, and the national pension service reviews the applicant's disability and determines the types and severity of disabilities.[16] People with disabilities were defined based on their disability registration status in the NHID. Our disability cohort included seven types of disabilities: (1) physical disability; (2) brain lesion disorder; (3) blindness or vision loss; (4) deafness or hearing loss; (5) intellectual disability; (6) autistic disorder; and (7) mental disability (Appendix pp 2–3).

This study also included a control group of people without disabilities by performing combined matching (propensity score-based 1:1 matching with an exact matching). Specifically, we considered age, income group, a province-level residential place, and four comorbidity variables (myocardial infarction or congestive heart failure, renal disease, dementia, and chronic pulmonary diseases) for 1:1 nearest neighbor propensity score matching, with exactly matched sex.

### Estimation of air pollutants

We obtained daily concentration estimates of ambient $PM_{2.5}$ (24-h average), ozone (maximum 8-h average), and $NO_2$ at a 1 $km^2$ spatial resolution across all districts in inland Korea. The modeled air pollutants were obtained from previously published studies using an machine-learning ensemble model (cross-validated $R^2$: 0.962 for $PM_{2.5}$, 0.967 for ozone, and 0.967 for $NO_2$ Appendix pp 4–11).[17] We calculated the daily mean concentrations of $PM_{2.5}$ and ozone for each district using these data. We applied a four-day moving average for $PM_{2.5}$ and ozone concentration (MA0-3): the day of ED admission and the previous three days (lag 0–3 d). We assigned this value to each enrollee based on the district of residence for each case day. Enrollees residing in the Jeju and Ulleung islands were excluded because of the unavailability of exposure modeling data.

### Statistical modeling

We assessed the risk estimate of ED admissions associated with a 10 $\mu g/m^3$ increase in $PM_{2.5}$ among people with disabilities (physical, intellectual, and mental disabilities; brain lesion disorders; blindness or vision loss; deafness or hearing loss; and autistic disorder) using a time-stratified case-crossover design. Since participants serve as their own controls, the design allows for the examination of potential short-term time-variant confounders while controlling for time-invariant confounding and adjusting for seasonality and long-term trends.[15] We defined the day of ED admission as the case day and selected control days with the same year, calendar month, and day of the week as the case day. We used a conditional logistic regression model to estimate the associations between short-term $PM_{2.5}$ and ED admissions. We assessed the difference in risk estimates between people with and without disabilities using the Wald test.

We included the following covariates in the model: federal holidays as a binary variable, MA0-3 ozone, and temperature. Temperature was adjusted using a distributed lag non-linear model (exposure–response curve with a natural cubic spline with four degrees of freedom, lag–response curve with a natural cubic spline with two internal knots, and a lag period of five days) to control for potential non-linear confounding of weather conditions.[18] To assess the results' robustness depending on the exposure value, we conducted multiple sensitivity analyses. First, we applied various lag structures of $PM_{2.5}$ and daily mean temperature. Second, we considered other models including different covariates: $NO_2$, relative humidity, and precipitation. Third, we restricted the analysis period to between 2015 and 2019 to exclude the COVID-19 period. Lastly, since ED admission could be repeated, we additionally considered a model addressing only the first visit per individual.

To express the association between $PM_{2.5}$ and ED admissions, we calculated the odds ratio (OR) for a 10 $\mu g/m^3$ increase in $PM_{2.5}$. To further quantify the ED admission case and cost burden due to $PM_{2.5}$, we estimated the annual increase in ED admission cases and costs attributable to $PM_{2.5}$ per 100,000 person-years. Using the estimated OR, the annual excess admission cases and costs were defined as $\alpha \times (1-1/OR)$, where $\alpha$ is the daily ED admission counts and corresponding costs respectively during the study period (2015–2021).[19] The excess ED admission cases and costs were calculated for days with an average $PM_{2.5}$ concentration. The 95% empirical confidence intervals (eCIs) were calculated using Monte Carlo simulations (Appendix p 12).[15]

To examine detailed associations between $PM_{2.5}$ and ED admissions, we performed stratified analyses by the cause of admission, sex, season, province, and the duration of disability registration. We classified ED admissions into four groups by the cause of admission, referring to the principal diagnostic codes in claims data from the NHID: cardiovascular diseases (ICD-10: I00–I99), genitourinary diseases (N00–N99), mental disorders (F00–F99), and respiratory diseases (J00–J99).[15] Further, we divided ED admissions into more detailed causes of admission (Appendix pp 13–16). The stratified analyses were based on sex, warm (March–August) and cold (September–February) seasons, 16 provinces, and the duration of disability registration (less than 12 years, 12–14 years, and more than 14 years), respectively.

We conducted data pre-process with SAS (Enterprise v7.1, SAS Institute Inc, Cary, NC) and statistical analysis with R (version 4.0.3; R development Core Team) with the packages "survival," "tsModel" and "spline."

### Role of the funder

The funders played no role in the study design, data collection, analysis, interpretation, or submission of the study.

## Results

Overall, 900,311 ED admissions from 2015 to 2021 were included among 3,624,590 persons with disabilities (Table 1 and Appendix p 17). The baseline rate of ED admissions and medical costs were higher in people with disabilities than in people without disabilities (Fig. 1 and Appendix p 18). Among people with disabilities, people with mental disability showed the highest baseline rate of ED admission, and people with brain lesion disorder showed the highest baseline cost. The district-level daily mean concentration of $PM_{2.5}$ from 2015 to 2021 was 22.44 μg/m$^3$ (Appendix pp 4–11). The mean age at ED admission among people with disabilities was 68.7 (standard deviation: 17.0) years (Appendix p 19). Age and sex were similar between the disability and control groups (Table 1). Cardiovascular diseases were the major cause of ED admissions for both people with and without disabilities (Table 1 and Appendix p 17).

| | With one of seven types of disabilities[a,d] (N = 900,311)[b] | Without disabilities[a] (N = 900,311)[b] |
|---|---|---|
| Age[c] | 68.7 (17.0) | 69.0 (17.5) |
| Sex | | |
| Male | 508,012 (56.4) | 508,012 (56.4) |
| Female | 392,299 (43.6) | 392,299 (43.6) |
| Cause of admission | | |
| Cardiovascular | 370,732 (41.2) | 456,445 (50.7) |
| Genitourinary | 157,558 (17.5) | 157,431 (17.5) |
| Mental | 117,314 (13.0) | 50,026 (5.6) |
| Respiratory | 254,707 (28.3) | 236,409 (26.3) |

SD: Standard deviation. [a]Mean with standard deviation or number with column percent. [b]Number of admissions through the emergency department (ED admission) from 2015 to 2021. [c]Age at ED admission. [d]Seven types of disabilities include physical disability, brain lesion disorder, blindness or vision loss, deafness or hearing loss, intellectual disability, autistic disorder, and mental disability. People without disabilities are matched samples of a cohort of people with disabilities based on sex and age.

***Table 1:*** **Descriptive statistics of admissions through the emergency department in South Korea, 2015–2021.**

Fig. 2 exhibits the association between $PM_{2.5}$ and total ED admissions, along with the annual excess ED admission cases and costs per 100,000 person-years. The association was more evident in people with disabilities (OR: 1.039 [95% CI: 1.036–1.042]) than in people without disabilities (OR: 1.022 [95% CI: 1.019–1.025]). Among people with disabilities, the association was prominent in people with mental disability, intellectual disability, and brain lesion disorders (OR: 1.081 [95% CI: 1.069–1.093]), 1.063 [1.047–1.079], and 1.045 [1.039–1.051] respectively) compared to people with other types of disabilities. People with mental disability showed the highest excess ED admission cases attributable to $PM_{2.5}$ (1268.9 cases [95% eCI: 1110.4–1420.2]) among seven types of disabilities. Excess ED admission costs were highest in people with brain lesion disorders (US$ 23,518,426 [95% eCI: 20,552,160–26,780,189]).

The association between $PM_{2.5}$ and ED admissions and excess ED admission cases and costs by cause of ED admission is presented in Figs. 3 and 4. The differences in the association between people with and without disabilities differed by cause of admission: ED admission by cardiovascular (OR: 1.037 [95% CI: 1.032–1.042]) and genitourinary diseases (OR: 1.015 [95% CI: 1.008–1.023]) showed greater associations in people with disabilities than in people without disabilities (OR: 1.018 [95% CI: 1.013–1.022] for cardiovascular diseases and 0.995 [95%CI: 0.987–1.003] for genitourinary disease). The highest association was observed in ED admission by mental disorder both in people with and without disabilities (1.085 [95%CI: 1.075–1.095]) for people with disabilities and 1.086 [95%CI: 1.071–1.100] for people without disabilities) even though the differences in the association between the two populations were not statistically evident. The excess ED admission cases and costs were higher in ED admission by cardiovascular diseases than other causes. For more detailed classifications of causes of admission, the risk estimates are higher in ED admission by pneumonia, dementia, schizophrenia, substance use disorders, and mood disorders than other causes within people with diabilities (Appendix pp 20–22). Due to the insufficient sample size of individuals with autistic disorder, we did not include these results in Fig. 4 but summarized them on page 23 of the Appendix. Wald test results showed statistically significant differences in risk estimates

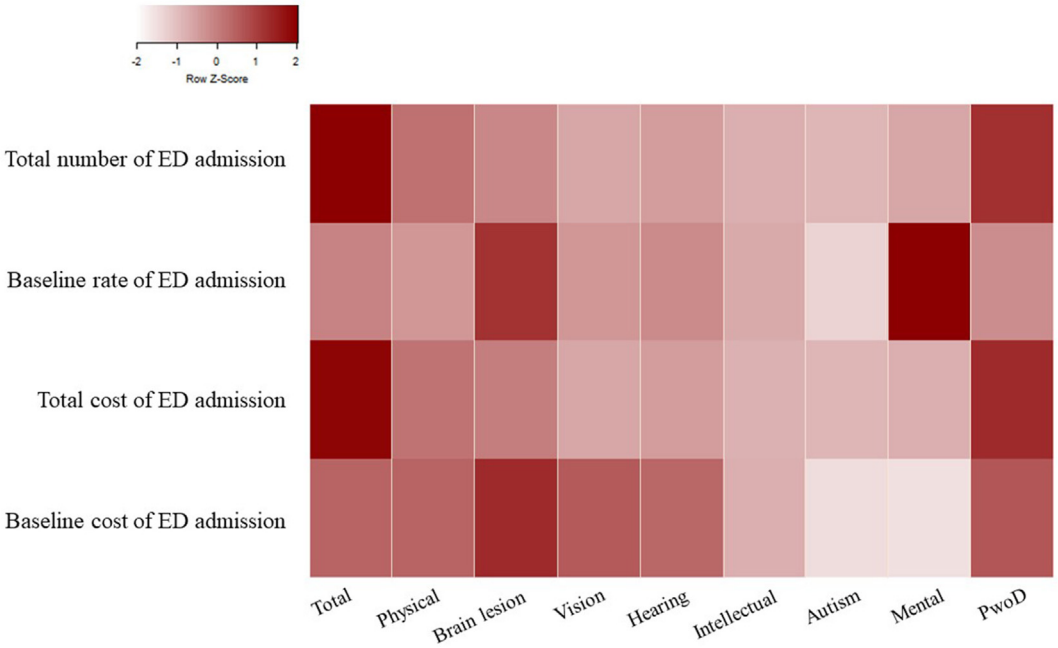


***Fig. 1:*** **Heat map of total number, cost, baseline rate, and baseline cost of admission through the emergency department by types of disabilities.** Data were standardized as a z-score within each row. Total = People with one of seven types of disabilities. Physical = Physical disability. Brain lesion = Brain lesion disorders. Vision = Blindness or vision loss. Hearing = Deafness or hearing loss. Intellectual = Intellectual disability. Mental = Mental disability. PwoD = People without disabilities.

between people with disabilities and their matched control groups in most disability types and ED admissions for cardiovascular or genitourinary diseases (Appendix p 24).

The risk estimates differed by the cause of ED admission and types of disabilities (Fig. 4). The risk estimates of ED admissions by mental disorders were higher than those of other causes of ED admissions for all types of disabilities. Annual excess ED admission cases were high in ED admission by cardiovascular diseases in people with brain lesion disorder (372.8 cases [95% eCI: 323.1–423.4 cases]) and ED admission by mental disorder in people with mental disability (1012.4 cases [95% eCI: 879.6–1146.1 cases]). These patterns were observed similarly in excess ED admission costs: US$ 16,493,346 [14,296,536–18,729,967] for ED admission by cardiovascular diseases in brain lesion disorder and US$ 11,058,025 [9,607,245–12,518,242] for ED admission by mental disorder in mental disability (Appendix p 25).

We found that the association between $PM_{2.5}$ and total ED admissions was generally higher in the warm season than in the cold season (Appendix p 26), in southeastern areas than others (Appendix pp 27–28), males than females, and in population with a shorter duration of disability registration than with a longer duration (Appendix p 29). Sensitivity analyses showed consistent results across various lag periods for exposure and covariates, including different lag periods for $PM_{2.5}$ (from MA0-3 to other exposure periods) and maximum lag periods of five to seven days for daily mean temperature. Additionally, other sensitivity analyses that considered various covariates and analysis periods demonstrated consistent results. We found that the OR decreased when only the first visits were analyzed (Appendix pp 30–31).

## Discussion

This study revealed that the association between short-term exposure to $PM_{2.5}$ and ED admission was higher in people with disabilities than people without disabilities, based on the nationwide data including over 6.5 million persons. Among people with disabilities, people with mental disability, intellectual disability, and brain lesion disorder showed a higher risk than other types of disabilities, and excess ED admission cases and costs were higher in people with brain lesion disorder and mental disability than other types of disabilities. The differences between people with and without disabilities were pronounced in ED admissions for cardiovascular and genitourinary diseases than in ED admissions for respiratory disease and mental disorders.

We conjecture that higher $PM_{2.5}$ associations in people with disabilities might be associated with their poorer health and socioeconomic conditions compared to those of people without disabilities. It is important to

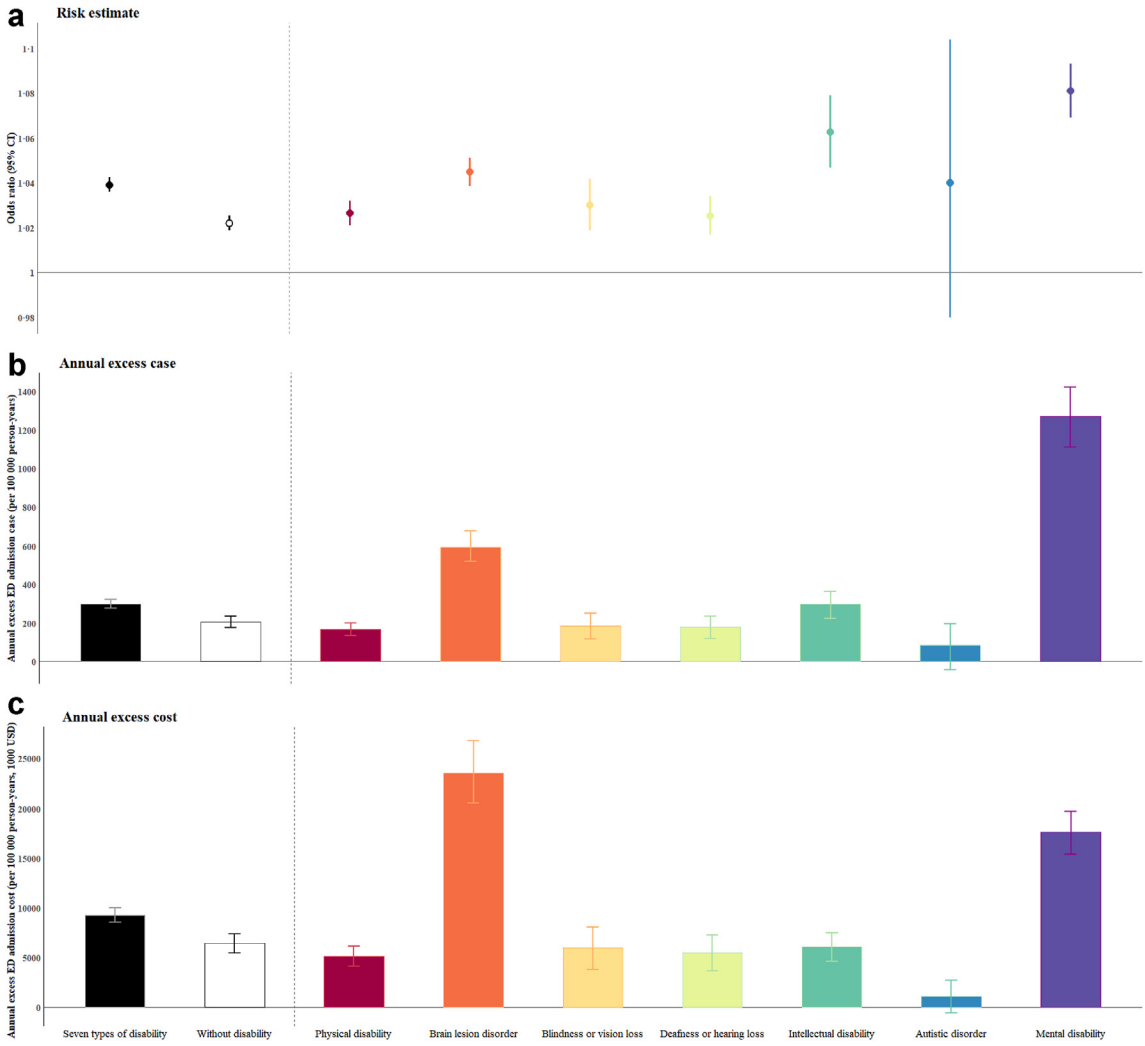


***Fig. 2:* Risk estimates of admissions through the emergency department and annual excess admission cases and costs attributable to $PM_{2.5}$.** (a) The risk estimates of admission through the emergency department (ED admission) were defined as the odds ratio (OR) per 10 μg/$m^3$ increase in $PM_{2.5}$. (b) Excess ED admission cases. (c) Excess ED admission costs. OR was calculated using a case-crossover design with conditional logistic regression. Excess cases and costs were calculated as α × (OR − 1)/OR, where α represents the baseline daily ED admission counts and costs per 100,000 person-years from 2015 to 2021. Error bars indicate a 95% CI or 95% empirical CI for estimates.

understand the interconnections between disability and marginalized subpopulations such as low-income, race, and unhealthy conditions from the perspective of environmental justice.[1,5] People with disabilities have substantial morbidity with 1.7 times higher chronic disease prevalence rate than people without disabilities in South Korea[20] and this pattern has been consistently observed in other countries.[11] Further, people with disabilities are more likely to experience disease exacerbation or not receive appropriate treatment compared to people without disabilities because of limited accessibility and availability of healthcare services.[9] People with disabilities might also encounter discrimination, chronic stress, and fewer opportunities to choose health-promoting behaviors, thereby increasing susceptibility to poor health.[21] These lower accessibility and chronic health conditions might contribute to the higher impact of $PM_{2.5}$.[10,12]

This study found that people with mental disability, intellectual disability, and brain lesion disorder showed a greater association between $PM_{2.5}$ and ED admissions compared to other disabilities. Proposed mechanisms for the impact of $PM_{2.5}$ are related to systemic oxidative stress, inflammation, particles or constituents in the circulation, autonomic nervous system imbalance,[22] and multimorbidity and low-income status which showed a higher association with hazardous impacts of $PM_{2.5}$.[23,24]

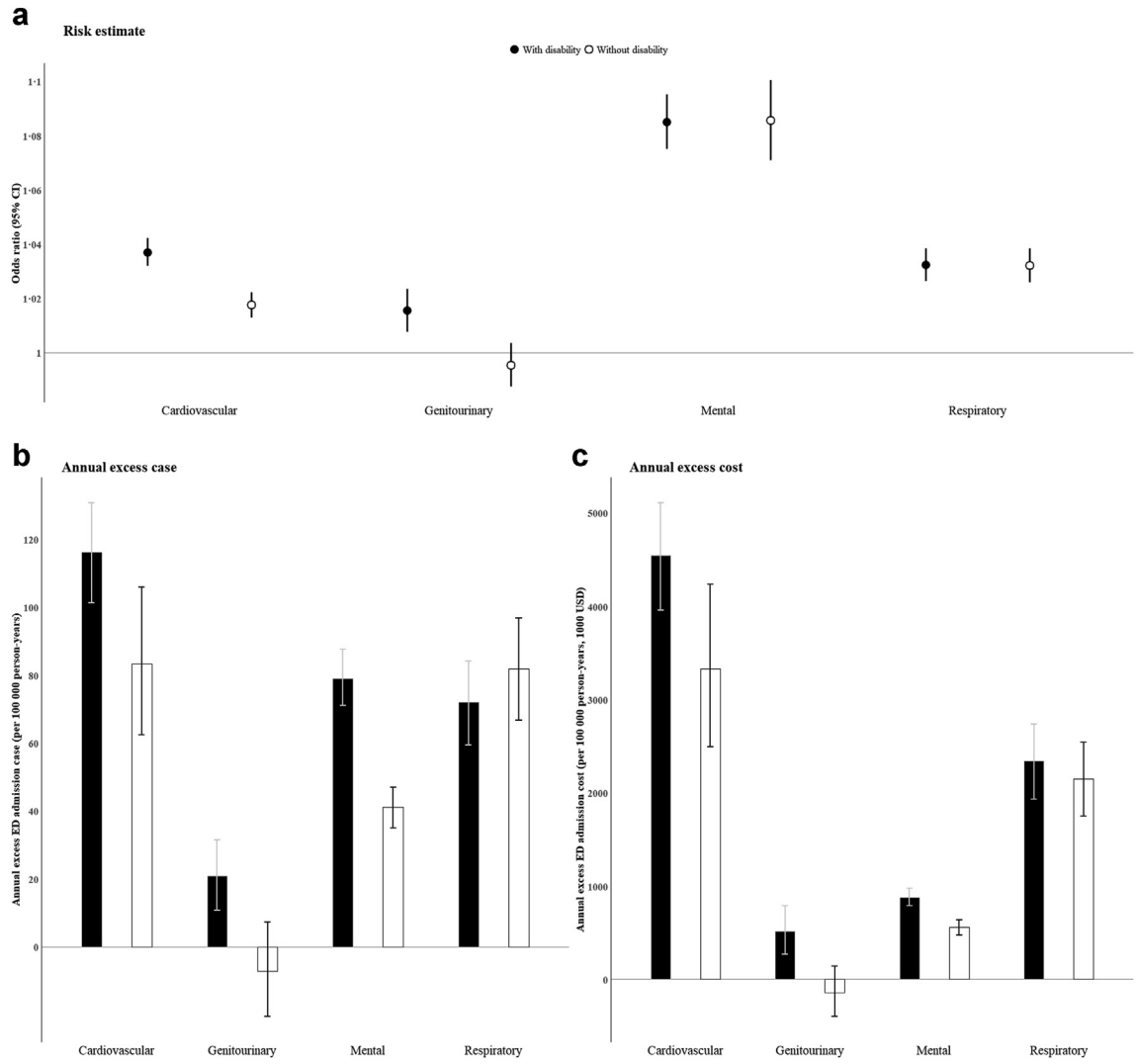


***Fig. 3*: Risk estimates of admissions through the emergency department and annual excess admission cases and costs attributable to $PM_{2.5}$ by causes of admission in people with and without disabilities.** (a) The risk estimates of admission through the emergency department (ED admission) were defined as the odds ratio (OR) per 10 μg/m$^3$ increase in $PM_{2.5}$. (b) Excess ED admission cases. (c) Excess ED admission costs. OR was calculated using a case-crossover design with conditional logistic regression. Excess cases and costs were calculated as $\alpha \times (OR - 1)/OR$, where $\alpha$ represents the baseline daily ED admission counts and costs per 100,000 person-years from 2015 to 2021. Error bars indicate a 95% CI or 95% empirical CI for estimates.

Thus, comorbidity conditions of people with brain lesion disorder may affect the higher association with $PM_{2.5}$.[5] Some brain lesion disorders may occur as sequelae of stroke; 74.4% of the brain lesion disorder population in our study had a history of stroke. Furthermore, lower income status of people with mental disability and intellectual disability than people with other types of disabilities may contribute to an increased risk of adverse health impacts of $PM_{2.5}$.[6] Within our study population, 45.2% of people with intellectual disability, and 63.4% of people with mental disability were classified into the low-income group (the lowest 15% income level based on health insurance premiums), while less than 25.0% of other types of disability population were classified as low-income.

The differences in ORs of ED admission attributable to $PM_{2.5}$ between the population with and without disabilities were prominent for admissions by cardiovascular diseases. Previous studies reported a higher association between $PM_{2.5}$ and hospital admission or mortality due to cardiovascular diseases in racial/ethnic minorities, those with certain comorbid conditions, and those at low socioeconomic status, compared to the total population.[2,19,22] Lower income status and a higher ratio

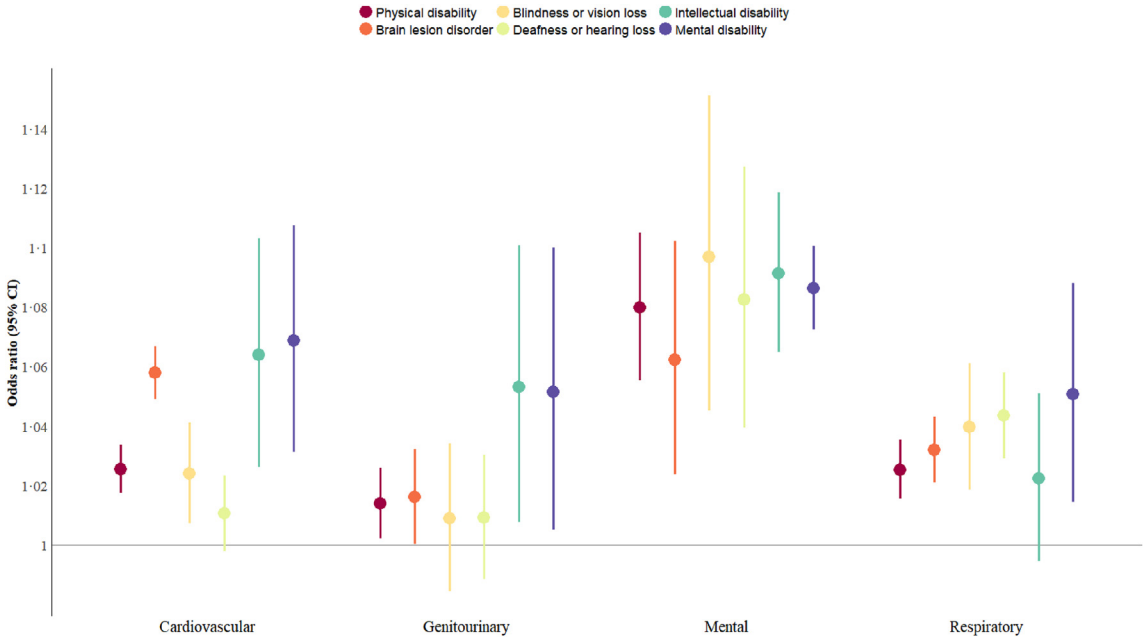


***Fig. 4:*** **Risk estimates of admissions through the emergency department attributable to $PM_{2.5}$ by causes of admission and types of disability.** The risk estimates were defined as the odds ratio (OR) per 10 μg/$m^3$ increase in $PM_{2.5}$ and calculated using a case-crossover design with conditional logistic regression. Error bars indicate a 95% CI for estimates.

of congestive heart failure among people with disabilities than people without disabilities (15.1% vs 14.7%) in our study population would be one of the factors for increasing the risk. In addition, old age (over 65 or 85 years) may act as an effect modifier to increase the health impact of $PM_{2.5}$,[24] and the population with disabilities showed three times higher aging rate than the population without disabilities in Korea.[25] The aging in the population with disabilities may also be associated with a higher risk estimate of ED admission attributable to $PM_{2.5}$ by cardiovascular disease than their counterpart without disabilities.

The association with ED admissions for genitourinary diseases was also more prominent in people with disabilities than in people without disabilities. Previous studies have reported a positive association between $PM_{2.5}$ and kidney diseases.[26] $PM_{2.5}$ may increase DNA damage and blood congestion in the kidneys, and decrease estimated glomerular filtration.[26] In our study population, people with disabilities showed a higher ratio of moderate-to-severe renal diseases than people without disabilities (5.5% vs 4.8% for people without disabilities). The higher medication usage in people with disabilities with high comorbidity rates[11] might exacerbate the oxidative stress and vasoconstrictive effects of $PM_{2.5}$, and they might affect the greater association between $PM_{2.5}$ and ED admissions for urinary diseases as the kidney is a vascularized organ.[26] People with disabilities face additional barriers to accessing reproductive healthcare due to limitations in medical instruments, which may further compromise their poor reproductive health.[27] This pre-existing health condition may amplify the impact of $PM_{2.5}$ on genital health of individuals with disabilities.

Unlike other causes of ED admissions, we observed the association between $PM_{2.5}$ and ED admission by mental disorders and respiratory diseases in both people with and without disabilities, although the difference was not prominent. This pattern appeared similarly in more detailed classifications of causes of admission (Appendix pp 20–22). A growing number of studies have revealed the impact of $PM_{2.5}$ on the decrease in cognitive function via the increase in stress hormones and the worsening of psychiatric conditions.[28] Mental and physical health interact–psychiatric disorders increase the risk for communicable and non-communicable diseases and at the same time, physical health conditions increase the risk of mental disorder or exacerbate the mental condition–increasing the importance of mental health.[29] It has been widely found that the mental health of people with disabilities is worse than that of people without disabilities.[30] Thus, the mental health gap between people with and without disabilities is one of the important social agendas. Although we could not find remarkable differences in the impact of $PM_{2.5}$ between these two populations, future studies should carefully examine the plausible mechanisms to explain this aspect with more developed study designs.

The excess ED admission cases and costs attributable to $PM_{2.5}$ in people with disabilities were higher in ED admissions for cardiovascular diseases. This was due to a higher baseline admission rate and cost of ED admission for cardiovascular diseases (Appendix p 32). The higher baseline rate and cost of cardiovascular diseases might be related to the high prevalence rates and substantial morbidity associated with cardiovascular diseases among people with disabilities.[20] In contrast, even though the baseline medical costs of the population with mental disability were the lowest among the seven types of disabilities, they showed higher excess medical costs than other disability types. A higher risk estimate in individuals with mental disability compared to those with other types of disabilities may contribute to this result. The medical costs of people with disabilities accounted for 17.4% of the total medical costs in Korea in 2020.[20] Thus reducing excess ED admission costs attributable to $PM_{2.5}$ also has significant public health implications.

This study has several strengths. First, to our knowledge, this is the largest study to assess the association between $PM_{2.5}$ and ED admissions in Korea for people with both physical and mental health needs and compare findings for people without disabilities. By considering different types of disabilities and causes of admission, our study provides insights into varying $PM_{2.5}$ impacts on hospitalization depending on the disability type, cause of ED admission, and disability status. Second, this study theoretically covered the entire registered Korean population with seven types of disabilities, and the findings may be generalizable for the population with disabilities. Because existing studies were limited in addressing various types of disabilities, our results may be useful for broader international communities for future research and more targeted action plans. Further, our estimated excess number of ED admission cases and costs attributable to $PM_{2.5}$ inform the quantitative burden of $PM_{2.5}$ and provide evidence for public health resource mobilizations.

This study had some limitations. First, we used district-level $PM_{2.5}$ concentration, as a proxy for personal exposure to $PM_{2.5}$, which could potentially lead to misclassification due to indoor/outdoor activity patterns and occupational exposure, which could differ between people with and without disabilities and by the types and severity of disabilities. Second, we defined cases based on claims data, so we may have missed some potential cases if beneficiaries did not visit the emergency department due to accessibility, financial, or other issues. Thus, we could not consider differences in accessibility or affordability issues, which may act as effect modifiers in the association between $PM_{2.5}$ and ED admission. Third, we could not consider the existence of multiple disabilities which may lead to even higher risk. Future studies may collect more information on co-disabilities to quantify the risk of such a population. Fourth, although repeated ED admissions may occur in the same individual, we could not account for recurrent admissions by adding a random intercept for each person due to computational constraints. Nonetheless, we found a positive association between $PM_{2.5}$ and ED admissions when including only the first visit for each individual, although the risk estimate was slightly weaker than the original. Lastly, we could not consider temporal changes in disability status within a short-term period and differences between dates of disability onsets and administrative registrations because the NHIS database only provides the year of the disability registration. We cautiously conjectured that many types of disabilities included in our study are chronic and likely occurred before registration in the NHIS database (in Korea, several months are required to register in general). Therefore, we carefully assumed that the possibility that the potential differences between the actual dates of disability onset and registration affected our risk estimates was small. However, we acknowledge that the temporal difference could generate biases in risk estimations, especially for several types of disabilities (such as limb amputation or stroke that might result in acute changes in disability status). Thus, future studies should importantly address this issue with extended data including accurate dates of disability occurrence and registration.

In conclusion, this study exhibited higher risk estimates of ED admission related to $PM_{2.5}$ in people with disabilities than in people without disabilities, and the differences were evident for ED admissions by cardiovascular and genitourinary diseases. In addition, within the population with disabilities, people with mental disability and brain lesion disorder showed a greater association with $PM_{2.5}$ and larger excess ED admission cases and costs attributable to $PM_{2.5}$ compared to other disabilities. In Korea, people with disabilities are not currently identified as high-risk individuals under the Environmental Health Act. Our findings support that people with disabilities need to be included as high-risk individuals in the law. Following this, exposure assessments to help identify different intervention points and more stringent policies against $PM_{2.5}$ for people with disabilities depending on disability types might be established.

#### Contributors

JP and WL conceptualized the study. WL and JP designed the methodology. JP and AK accessed, analyzed, and verified the data. JP, AK, SA, SK, DK, CK, JO, and the AiMS-CREATE team collected the data. WL acquired the funding for this study. WL and HK supervised the study. JP wrote the original draft. AK, MLB, ZAA, HK, and WL reviewed and edited the manuscript. HK and WL were responsible for the decision to submit the manuscript. All authors had full access to the study results except authors originating from a country other than South Korea who were not able to access the raw claim data owing to regulatory restrictions.

### Data sharing statement

Satellite-derived ERA5-land dataset for temperature are publicly available through the Google Earth Engine website, available at: [https://earthengine.google.com/]. Use of healthcare resources and associated costs of all beneficiaries from the National Health Insurance Database cannot be made publicly available, but can be accessed through a formal data request process and after approval by National Health Insurance Service.

### Code sharing statement

A sample of the analysis code is available from https://github.com/pjapja0823/DSB_PM/tree/main.

### Declaration of interests

MLB reports receiving consulting fees from Clinique and ToxiMap, honorariums for speaker from Colorado School of Public Health, Duke University, University of Texas, Data4Justice, Korea University, UPenn, honorariums for editorial duties from IOP Publishing, honorarium for grant review from NIH, Health Canada, EHS, PAC-10, UKRI, AXA Research Fund Fellowship, University of Texas, honorarium for research from Korea University, for external advisory committee from Harvard University and University of Montana, for online survey/workshop from SciQuest, travel reimbursement from Colorado School of Public Health, University of Texas, Duke University, Harvard University, American Journal of Public Health, Columbia University, CMAS conference, Nature conference, honorarium from US EPA Clean Air scientific advisory committee. The other authors declare no conflict of interest.

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### Appendix A. Supplementary data

Supplementary data related to this article can be found at https://doi.org/10.1016/j.lanwpc.2024.101256.

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