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Ambient $PM_{2.5}$ and risk of hospital admissions: Do risks differ for men and women?

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Abstract

Background—While strong evidence exists for associations between fine particles ($PM_{2.5}$) and health, less is known about whether associations differ by sex.

Methods—We used Bayesian hierarchical modeling to estimate associations between $PM_{2.5}$, based on ambient monitors, and risk of cause-specific cardiovascular and respiratory hospitalizations for about 12.6 million Medicare beneficiaries (≥65 years) residing in 213 U.S. counties for 1999–2010.

Results—Point estimates were higher for women than men for almost all causes of hospitalization. $PM_{2.5}$ risks were higher for women than men for respiratory tract infection, cardiovascular, and heart rhythm disturbance admissions. A 10 μg/m^3 increase in same-day $PM_{2.5}$ was associated with a 1.13% increased risk of heart rhythm disturbance admissions for women (95% posterior interval: 0.63%, 1.63%), and 0.03% for men (95% PI: −0.48%, 0.55%). Differences remained after stratification by age and season.

Conclusions—Women may be more susceptible to $PM_{2.5}$-related hospitalizations for some respiratory and cardiovascular causes.

Fine particulate matter ($PM_{2.5}$) was estimated to cause 13,000 deaths in 2005 in the continental U.S.[1] and 3.7 million deaths/year globally.[2] In the U.S., over 74 million people reside in areas exceeding health-based $PM_{2.5}$ standards.[3] Despite this substantial health burden, less is known about whether some people face higher risks. The Clean Air Act requires the U.S. Environmental Protection Agency (EPA) to set standards with an adequate margin of safety for sensitive individuals. Thus, understanding who is most susceptible has both scientific and decision-making relevance. A recent review of effect modifiers of particulate matter associations found that most studies of hospital admissions (13 of 14) did not identify statistically significant evidence of different effects by sex,[4] and concluded that current literature indicates weak evidence of higher $PM_{2.5}$ mortality risk for women than men. A study in 9 Italian cities of particulate matter with aerodynamic diameter ≤10μm (PM_{10}) found higher risk of heart failure hospitalizations in women than in men, but higher

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risk of arrhythmia hospitalizations in men.[5] There exists no consensus on whether sex is an effect modifier for health consequences of particles, and if so which health outcomes are most affected. We conducted a multi-site time-series analysis of short-term $PM_{2.5}$ exposure and cardiovascular and respiratory hospital admissions among older persons to examine whether effects differ by sex.

Methods

Daily hospital admissions data for Medicare fee-for-service beneficiaries ≥65y were obtained from the Medicare Claims Inpatient Files for 213 U.S. counties, 1999–2010, and appropriate Institutional Review Board (IRB) approvals were obtained. These data have been used in previous studies to investigate air pollution and risk of hospital admissions as part of the Medicare Air Pollution Study (MCAPS).[6–9] For this work, we selected the following variables from the Medicare billing claims: sex, age, county of residence, and cause of hospital admissions. Sex was self-reported. Causes of admissions were based on International Classification of Disease, Ninth Revision, Clinical Modification (ICD-9-CM) principal discharge diagnosis codes for cardiovascular causes: heart failure (428), heart rhythm disturbances (426–427), cerebrovascular events (430–438), ischemic heart disease (410–414, 429), peripheral vascular disease (440–448), and acute myocardial infarction (410, omitting 410.x2); and respiratory outcomes: chronic obstructive pulmonary disease (COPD, 490–492), respiratory tract infections (464–466, 480–487), and asthma (493). We considered outcomes both separately and as “total” cardiovascular and respiratory admissions by summing the selected admissions.

Daily county-level $PM_{2.5}$ values were estimated using population-based monitors in that county from the U.S. EPA Air Quality System. On average, county-level $PM_{2.5}$ estimates were available for 56.5% of study days (median 49.0%, range 7.8%–99.9%). For each county and day, we averaged $PM_{2.5}$ measurements for monitors within that county. All exposure estimates were based on measurements, and missing data were not imputed. More information is available elsewhere.[7,9]

We used Bayesian hierarchical modeling to estimate county-specific and overall associations between $PM_{2.5}$ and admissions. The stage-one county-specific model adjusted for weather (temperature, dew point, previous days’ temperature and dew point), day-of-the-week, and temporal trends, and included an offset for the number of beneficiaries at risk. Degrees of freedom were 6 for temperature, 3 for dew point, and 8/year for time. Similar methods were used previously.[6–8] Fewer counties were included for some hospitalization causes due to frequency of events and convergence concerns. Separate effects for men and women were estimated through stratification. Effect estimates for single-day lags of the same day (lag 0), previous day (lag 1), and two days previous (lag 2) were modeled separately. We investigated effects by season with interaction models[9] and by region with stratification. Analyses were conducted in R Version 2.15.1.

Results

Summary statistics for environmental variables ($PM_{2.5}$, weather) are shown in Supplemental Table S1. Supplemental Tables S2 and S3 summarize the study population of approximately 12.6 million persons. Baseline hospitalization rates for asthma were higher for women than men; for other causes of hospitalization, baseline rates were similar by sex or higher for men.

Table 1 and Supplemental Figure S1 show results for lag 0 by cause of hospitalization for men, women, and the total population. Overall associations were observed for total respiratory and cardiovascular hospitalizations, and cardiovascular causes of heart failure, cerebrovascular disease, heart rhythm disturbance, and peripheral vascular disease. For men and women separately, associations remained for these cardiovascular causes. For respiratory admissions, $PM_{2.5}$ was associated with total respiratory admissions and respiratory tract infection for women but not men.

Associations were generally strongest, with the highest and most certain estimates, for lag 0 than other lags for most causes. Subsequent analyses were conducted for lag 0; with sensitivity analyses for other lags (Supplemental Tables S4 and S5).

Central effect estimates for $PM_{2.5}$ were higher among women than men for all respiratory causes of hospitalization except COPD (Table 1). A 10μg/m^3 increase in $PM_{2.5}$ was associated with a 0.51% increase (95% posterior interval (PI) 0.15%, 0.87%) in hospitalizations for respiratory tract infection for women, compared to −0.11% (95% PI −0.56%, 0.34%) for men, corresponding to an estimated relative risk ratio[10] (RRR) of 1.006 (95% CI 1.0004, 1.01). For total cardiovascular disease, $PM_{2.5}$ was associated with a 0.43% increased risk of hospitalization (95% PI 0.21%, 0.65%) for men and 0.84% increased risk (95% PI 0.59%, 1.09%) for women per 10μg/m^3 $PM_{2.5}$ (RRR 1.004, 95% CI 1.0008, 1.007). For heart rhythm disturbance admissions, risk increased 1.13% (95% PI 0.63%, 1.63%) per 10 μg/m^3 $PM_{2.5}$ for women and 0.03% (95% PI −0.48%, 0.55%) for men (RRR 1.01, 95% CI: 1.004, 1.02).

For causes of hospital admissions for which effect estimates were different by sex (respiratory tract infection, total cardiovascular, and heart rhythm disturbance), we performed analysis by age (Table 2, Supplemental Table S6). Central estimates were higher for women than men for all considered causes of admissions and age strata, except for similar estimates for those 65–74y for total cardiovascular admissions. Risk estimates were higher for women than for men for cardiovascular admissions for those 75–84y. We also investigated effects by age for other causes of admissions (results not shown), and effect estimates were higher for women than men for heart failure admissions.

For the selected hospitalization causes, central effect estimates were higher for women than men for all seasons (Table 3) and regions (Table 4). Differences in risk by sex were highest in winter with higher effects for women for respiratory tract infection (RRR 1.01, 95% CI: 1.0, 1.02), total cardiovascular admissions (RRR 1.005, 95% CI: 1.0, 1.01), and heart rhythm disturbance (RRR 1.01, 95% CI: 1.0, 1.03). Risks were higher for women than men for the Northeast for total cardiovascular admissions (RRR 1.008, 95% CI: 1.001, 1.02) and heart rhythm disturbance admissions (RRR 1.02, 95% CI: 1.003, 1.04).

Discussion

In our study, hospitalization risks for same-day $PM_{2.5}$ were higher for women than men for some respiratory and cardiovascular causes. Our results are consistent with a qualitative review finding weak evidence of higher particulate matter mortality in adults for women than men.[11] Several earlier works on PM_{10} and hospitalizations found no evidence of differences by sex, with most studies on a single city or area[12–19] and some studies of 7 to 21 cities.[20–22] A study of 9 Italian cities found higher PM_{10} effects for men for arrhythmias and for women for heart failure admissions.[5] A few studies examined $PM_{2.5}$ hospitalizations, finding no differences by sex for Toronto,[23] Utah's Wasatch Front,[24] and 7 Chilean urban areas.[25]

Our findings indicate that increased $PM_{2.5}$ is associated with a higher relative (i.e., percentage) increase in hospitalizations for women than men. Errors can occur in discharge diagnostic codes;[26,27] however, such errors are unlikely to differ by daily pollution patterns or sex, and therefore are unlikely to result in our findings. We observed higher estimates for women than men for respiratory tract infection, but not COPD, and for heart rhythm disturbances, but not other cardiovascular causes. The number of hospitalizations for respiratory tract infection were almost twice that for COPD; however, heart rhythm disturbance admissions were 60%–80% those for heart failure, cerebrovascular disease, or ischemic heart disease. Thus, statistical power does not explain the observed differences in effects by sex for some causes of hospitalization and not others.

Differences in health by sex are affected by structural, behavioral, and psychosocial determinants of health that relate to socio-economics, social support, stress, and family structure, as well as lifestyle choices such as smoking, drinking, exercise, and diet.[28] A study of persons ≥65y found higher prevalence of frequent mental distress in women than men.[29] The biologic mechanisms through which air pollution may impact men and women differently may relate to the pathways through which smoking has different effects by sex. Smoking can have higher impacts on pulmonary function, myocardial infarction, and coronary heart disease in women than men, although results are not consistent across studies.[30–33] Such differences may relate to size of airways, genetic, or hormonal differences.

Men and women may have different exposures, which are affected by activity patterns. Older women spent more time outside than men in Los Angeles, but not Baltimore.[34] In a U.K. study of persons ≥65 y, activity levels were higher for women indoors and men outdoors.[35] For U.S. persons ≥60 y, women spent more time in non-sedentary activities than men.[36] Differences by sex may also exist for co-morbidities, diet, and other air pollution exposures (e.g., cooking, transportation[37]). Older men are more likely than older women to be employed, although the fraction of older persons in the workforce is increasing for women and decreasing for men.[38]

The specific mechanisms through which women have higher $PM_{2.5}$ risks should be explored in further research. Other work could investigate whether different effect estimates by sex vary by the chemical structure of particles or other potential effect modifiers, and address the limitations in this work such as community-level exposure. Results suggest different pathways through which short-term $PM_{2.5}$ exposure affects health in men and women.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Table 1

Percent increase in risk of hospital admissions associated with 10μg/m^3 increase in $PM_{2.5}$, for same day exposure at Lag 0 (95% posterior interval)

Disease	Male	Female	Total
Respiratory	0.03 (−0.32, 0.38)	0.41 (0.12, 0.70)	0.25 (0.01, 0.48)
Respiratory tract infection	−0.11 (−0.56, 0.34) [1]	0.51 (0.15, 0.87) [1]	0.21 (−0.07, 0.49)
COPD	0.41 (−0.18, 1.00)	0.37 (−0.15, 0.88)	0.34 (−0.05, 0.74)
Asthma [2]	0.16 (−1.76, 2.12)	0.18 (−0.93, 1.31)	0.08 (−0.84, 1.01)
Cardiovascular	0.43 (0.21, 0.65) [3]	0.84 (0.59, 1.09) [3]	0.65 (0.48, 0.83)
Heart failure	0.87 (0.45, 1.29)	1.38 (0.95, 1.81)	1.13 (0.82, 1.45)
Cerebrovascular disease	0.72 (0.20, 1.25)	0.58 (0.16, 1.00)	0.65 (0.30, 0.99)
Heart rhythm disturbance	0.03 (−0.48, 0.55) [4]	1.13 (0.63, 1.63) [4]	0.61 (0.25, 0.96)
Peripheral vascular disease [2]	1.59 (0.47, 2.72)	1.15 (0.14, 2.16)	1.26 (0.48, 2.05)
Ischemic heart disease	0.11 (−0.26, 0.49)	0.27 (−0.09, 0.64)	0.18 (−0.09, 0.45)
Acute myocardial infarction	0.31 (−0.24, 0.85)	0.28 (−0.24, 0.80)	0.27 (−0.11, 0.65)

[1] For respiratory tract infection, RRR 1.006 (95% CI: 1.0004, 1.01). The RRR (relative risk ratio) is the ratio of relative risk for women to the relative risk for men.[10]

[2] Asthma 77 counties included; peripheral vascular disease 140 counties; all other causes 213 counties.

[3] For cardiovascular disease, RRR 1.004 (95% CI: 1.0008, 1.007).

[4] For heart rhythm disturbance, RRR 1.01 (95% CI: 1.004, 1.02).

Table 2

Percent increase in risk of hospital admissions for 10μg/m^3 increase in $PM_{2.5}$, for same day exposure at Lag 0, by age (95% posterior interval)

	Male	Female	Total
Respiratory tract infection			
65–74 y[1]	−0.12 (−0.88, 0.64)	0.23 (−0.51, 0.98)	0.02 (−0.50, 0.54)
75–84	0.13 (−0.56, 0.83)	0.50 (−0.07, 1.08)	0.26 (−0.18, 0.71)
≥85[1]	−0.01 (−0.86, 0.86)	0.78 (0.14, 1.42)	0.45 (−0.09, 0.98)
Cardiovascular			
65–74	0.55 (0.20, 0.91)	0.54 (0.16, 0.92)	0.54 (0.28, 0.80)
75–84	0.29 (−0.04, 0.62)[2]	0.79 (0.46, 1.12)[2]	0.54 (0.30, 0.78)
≥85	0.61 (0.10, 1.12)	1.07 (0.70, 1.45)	0.92 (0.61, 1.24)
Heart rhythm disturbance			
65–74[1]	0.25 (−0.65, 1.15)	0.89 (−0.02, 1.80)	0.44 (−0.19, 1.07)
75–84	−0.05 (−0.85, 0.76)	0.92 (0.21, 1.63)	0.43 (−0.10, 0.97)
≥85[1]	0.42 (−0.86, 1.71)	1.74 (0.84, 2.65)	1.28 (0.53, 2.04)

[1]Respiratory tract infection 65–74y 196 counties included, ≥85y 205 counties; heart rhythm disturbance 65–74y 190 counties, ≥85y 135 counties; all other causes 213 counties.

[2]For cardiovascular disease for those 75–84y, RRR 1.005 (95% CI: 1.0003, 1.01). The RRR (relative risk ratio) is the ratio of relative risk for women to the relative risk for men.[10]

Table 3

Percent increase in risk of hospital admissions for 10μg/m^3 increase in $PM_{2.5}$, for same day exposure at Lag 0, by season (95% posterior interval). All 213 counties were included for all causes of hospitalization.

	Male	Female	Total
Respiratory tract infection			
Winter	−0.18 (−1.19, 0.85)	0.85 (−0.06, 1.77)	0.40 (−0.29, 1.10)
Spring	0.56 (−0.59, 1.73)	0.96 (−0.06, 1.99)	0.80 (0.02, 1.58)
Summer	−0.14 (−1.30, 1.02)	0.12 (−0.93, 1.17)	0.01 (−0.78, 0.81)
Fall	−0.56 (−1.35, 0.24)	0.24 (−0.43, 0.92)	−0.13 (−0.66, 0.39)
Cardiovascular			
Winter	0.95 (0.42, 1.48)	1.48 (1.00, 1.96)	1.25 (0.89, 1.62)
Spring	0.71 (0.14, 1.28)	0.88 (0.37, 1.39)	0.81 (0.42, 1.19)
Summer	0.21 (−0.34, 0.76)	0.34 (−0.14, 0.83)	0.28 (−0.09, 0.66)
Fall	−0.02 (−0.37, 0.33)	0.35 (−0.02, 0.73)	0.20 (−0.07, 0.47)
Heart rhythm disturbance			
Winter	0.72 (−0.60, 2.05)	2.10 (0.97, 3.24)	1.51 (0.65, 2.37)
Spring	0.97 (−0.42, 2.37)	1.08 (−0.10, 2.28)	1.08 (0.17, 2.00)
Summer	−0.71 (−2.02, 0.63)	0.56 (−0.56, 1.70)	0.06 (−0.80, 0.93)
Fall	−0.47 (−1.29, 0.35)	0.50 (−0.25, 1.25)	0.02 (−0.54, 0.58)

Table 4

Percent increase in risk of hospital admissions for 10μg/m^3 increase in $PM_{2.5}$, for same day exposure Lag 0, by region[1]

	Male	Female	Total
Respiratory tract infection			
Northeast	0.46 (−0.58, 1.51)	0.89 (0.00, 1.78)	0.69 (0.02, 1.36)
Midwest	−0.34 (−1.27, 0.61)	0.64 (−0.21, 1.49)	0.18 (−0.44, 0.80)
South	0.11 (−0.83, 1.06)	0.40 (−0.37, 1.17)	0.24 (−0.38, 0.86)
West	−0.74 (−1.70, 0.23)	0.46 (−0.58, 1.51)	0.89 (0.00, 1.78)
Cardiovascular			
Northeast	0.71 (0.24, 1.18) [2]	1.53 (1.02, 2.05) [2]	1.16 (0.82, 1.50)
Midwest	0.41 (−0.05, 0.88)	0.49 (0.05, 0.93)	0.45 (0.12, 0.79)
South	0.43 (−0.03, 0.89)	0.68 (0.16, 1.19)	0.53 (0.15, 0.91)
West	0.15 (−0.36, 0.66)	0.40 (−0.11, 0.91)	0.27 (−0.09, 0.62)
Heart rhythm disturbance			
Northeast	−0.21 (−1.34, 0.93) [3]	1.68 (0.53, 2.85) [3]	0.82 (0.08, 1.56)
Midwest	0.34 (−0.78, 1.48)	1.27 (0.20, 2.35)	0.84 (0.05, 1.64)
South	0.56 (−0.48, 1.62)	1.03 (0.10, 1.97)	0.81 (0.12, 1.50)
West	−0.67 (−1.97, 0.64)	0.62 (−0.64, 1.90)	−0.03 (−0.91, 0.86)

[1]Region specifications are as follows. States in parentheses are not included in analyses. Northeast (51 counties): ME, NH, (VT), MA, RI, CT, NY, PA, and NJ. Midwest (53 counties): WI, MI, IL, IN, OH, MO, (ND), (SD), NE, KS, MN, and IA. South (76 counties): DE, MD, DC, VA, WV, NC, SC, GA, FL, KY, TN, MS, AL, OK, TX, AR, and LA. West (33 counties): ID, (MT), (WY), NV, UT, CO, Aa, NM, WA, OR, and CA.

[2]For cardiovascular disease in Northeast, RRR 1.008 (95%: 1.001, 1.02).

[3]For heart rhythm disturbance in Northeast, RRR 1.02 (1.003, 1.04).