Ozone-related respiratory morbidity in a low-pollution region

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Abstract

Objective—We evaluated the effects of ozone on respiratory-related hospital admissions in three counties in Washington State from 1990 – 2006. We further examined vulnerability to ozone by key demographic factors.

Method—Using linked hospital admission and ambient monitoring data, we estimated the age-, sex-, and health insurance-stratified associations between ozone (0-3 days' lag) and respiratory-related hospital admissions in King, Spokane, and Clark County, Washington.

Results—The adjusted relative risk (RR) for a 10 ppb increase in ozone at 3 days' lag was 1.04 (95% confidence interval [CI]: 1.02, 1.07) for Clark County, 1.03 (95% CI: 1.01, 1.05) for Spokane County, and 1.02 (95% CI: 1.01, 1.03) for King County. There was consistent evidence of effect modification by age.

Conclusion—Ozone at levels below federal standards contributes to respiratory morbidity among high-risk groups in Washington.

Introduction

Ozone is a highly reactive air pollutant that can irritate airways, decrease pulmonary function, and initiate inflammatory responses.[1–5] Even at relatively low levels or for short durations, exposure to ambient ozone contributes to an increase in respiratory-related hospital admissions,[6–8] particularly among certain subpopulations. Adults aged 65 years and older may be more susceptible to ozone due to comorbidities and age-related natural declines in lung function,[9] whereas children may be more susceptible due to incomplete lung development, higher respiratory rates, and an increased lung surface area to body

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weight ratio as compared to adults.[10] Despite the abundance of literature, it is not clear whether these groups are at an increased risk for respiratory-related hospital admissions associated with ozone. Based on the results of a recent meta-analysis, only 30% of the published studies reported higher associations among older adults, aged 65 years and older, as compared to younger adults.[11] Even fewer studies report a statistically significant increase in risk for respiratory-related hospital admissions associated with ozone among children, aged 0–18 years.[12–15]

Other subpopulations may experience a higher health risk associated with ozone exposure, but research examining increased susceptibility by socio-demographic factors is limited. Epidemiologic research indicate a stronger association between ozone and adverse respiratory health outcomes among individuals with lower socioeconomic indicators, in terms of education level or employment.[11] However, no published studies have evaluated the potential differences by health insurance status. Furthermore, it is not clear whether these associations vary by sex.[11] More research is needed to understand which socio-demographic populations may be most sensitive to ozone.

Using hospital admissions data for three geographically and climatalogically distinct counties in Washington State, we investigated the association between ozone and respiratory-related hospital admissions in areas that are below the National Ambient Air Quality Standards for ozone. Additionally, we estimated the age-, sex-, and health insurance-stratified associations between ozone and respiratory-related hospital admissions.

Methods

Hospital admissions for Respiratory Conditions

Hospital admissions data for respiratory conditions were obtained from the Washington State Comprehensive Abstract Reporting System (CHARS) for study years 1990–2006. Information on date of the hospital admission, primary International Classification of Diseases (ICD-9) code, demographic characteristics (patient's sex, age, and health insurance provider), and county of residence were included in this database. Race/ethnicity was not available in the dataset. Hospital admissions with a primary ICD-9 code classified under diseases of the respiratory system (460–519) were considered for our analysis. This group includes acute respiratory infections (460–466), other diseases of the upper respiratory tract (470–478), pneumonia and influenza (480–488), chronic obstructive pulmonary disease (COPD) and allied conditions (490–496), lung diseases due to external agents (500–508), and other diseases of the respiratory system (510–519). Only hospital admissions that were classified as "emergency" or "urgent" were included in our analyses; other admissions types (e.g. elective procedure) were excluded from the analysis.

Ozone

Daily maximum 8-hour ozone concentrations were obtained from Washington State Department of Ecology monitoring stations in King County (n=8), Spokane County (n=2), and Clark County (n=2). Additional ozone data were collected from Oregon Department of Environmental Quality for Multnomah, Columbia and Clakamas counties (n=5), located in

the same airshed as Clark County. Ozone was monitored hourly from May 1st through September 30th of each calendar year. To be included in our analyses, monitors were required to have at least 75% of the days in a month with available data.

Particulate Matter

Daily average concentrations of coarse particulate matter (PM_{10}) were collected from the United States Environmental Protection Agency (EPA) Air Quality System Data Mart for the entire duration of the study period. Average daily PM_{10} concentrations ($\mu g/m^3$) were typically measured every sixth day. To address days in which data were not available, we created moving averages of PM_{10} values based on the nearest prior value and nearest future value. Fine particulate matter ($PM_{2.5}$) was not included in this analysis because the EPA did not begin to systematically collect $PM_{2.5}$ until 1999.

Humidex

Meteorological data consisted of daily temperature and humidity for different points of the Variable Infiltration Capacity (VIC) macroscale hydrologic simulation model in the Pacific Northwest.[16] Each VIC point is a unique 4 kilometer by 4 kilometer grid that assimilated daily or sub-daily meteorological observations. Humidex, a combined measure of temperature and humidity, was calculated to quantify the combined effects of temperature and humidity on the human body.[17] The average of the daily maximum humidex value was calculated for all VIC points to obtain a county-wide daily maximum humidex value as a single exposure measure for each day.

Statistical Methods

Proportions of individual characteristics and Pearson correlations of the environmental exposure measurements were performed for King, Clark, and Spokane County, separately. We performed time-series analyses using the linked ozone and hospital admission data for the years 1995–2006. From these data, a daily time-series for ozone, PM_{10}, and humidex were calculated. Regression models were performed for each county separately.

Poisson regression models were used to evaluate the relation between ozone at 0, 1, 2, and 3 days' lag and daily counts of respiratory-related hospital admissions. Semi-parametric generalized additive models were implemented in the analysis. Generalized additive models implemented b-splines and local regression methods for the univariate smoothing components, using the generalized cross-validation method to select the smoothing parameter.[18] Based on analysis of deviance, a smoothed parameter for time trend was included in the model; ozone, PM_{10}, and daily maximum humidex were entered into the model as linear functions. Though daily average humidex and daily maximum humidex were both available, only maximum humidex was included in the model. Although inclusion of either daily average temperature or maximum daily temperature are both found in the literature, maximum daily temperature has been shown to play a role in heat-related morbidity and mortality.[19] The final model adjusted for date (spline), day of week (indicator), ozone at 0–3 days' lag, maximum humidex at 0–3 days' lag, and mean PM_{10} at 0 days' lag.

To examine susceptibility by certain subpopulations, we stratified the associations between ozone and respiratory-related hospital admissions by sex, age (0–4 years, 5–14 years, 15–44 years, 45–64 years, 65–84 years, and 85+ years), and health insurance provider (Medicaid, Medicare, health maintenance organization (HMO)/Private, Labor & Industries [a statewide workers compensation program], self-pay, health care services contractor, and other). Relative risks (RRs) and 95% confidence intervals (CIs) were estimated for 10 ppb increases in ozone.

Sensitivity Analyses

Because children and older adults may be particularly susceptible to the adverse respiratory effects of ozone, we evaluated the association between ozone and specific respiratory conditions that are common to each group in separate models. For children (aged 0–14 years), we selected diagnostic categories that are common among children, including croup (464.4), pneumonia (480–486), asthma (493), and bronchitis/bronchiolitis (466, 490, 491) [20]. For older adults (aged 65+ years), we investigated hospital admissions for pneumonia (480–486), influenza (487), bronchitis (466) and COPD and allied conditions (490–496).

All analyses were conducted using SAS version 9.2. Analyses were approved by the Institutional Review Boards at the University of Washington and Colorado State University.

Results

Hospital admissions for respiratory conditions

A total of 104,468 hospital admissions for respiratory conditions were collected for the warm season months (May 1 through September 30), with a majority of the visits occurring in King County (Table 1). Of these visits, 88.5% were classified as urgent care or emergency visits. Compared to Clark County, King County had slightly more hospital admissions among women than Clark and Spokane County and more hospital admissions among children, aged 0–14 years. For all three counties, Medicare recipients and adults, aged 65+ years, represented the highest proportion of respiratory hospital admission. Pneumonia and influenza were the most common underlying conditions for the hospital admission within each county. Among children, aged 0–14 years, asthma was the most common underlying condition for the hospital admission in King and Clark Counties, while pneumonia was the most common underlying condition for the hospital admission in Spokane County.

Ozone

The mean 8-hour daily maximum ozone for the study period was 34.8 ppb (standard deviation [SD]=13.3), 41.4 ppb (SD=20.0), and 45.8 (SD=10.0) for King, Clark, and Spokane County, respectively (Table 2). The mean 1-hour and 8-hour values of ozone have remained stable for King County over the study period, whereas the mean values decreased in Clark County since 1990 and increased in Spokane County since 2000. Correlations between ozone measurements were moderate to strong for the King County monitors (correlation coefficients ranging from 0.50 to 0.97) and for the Clark County area monitors

(correlation coefficients ranging from 0.57 to 0.95); the two monitors for Spokane County were strongly correlated (correlation coefficient: 0.83).

Relationship of Environmental Exposures

The correlations between environmental exposures indicated weak to strong correlations. For King County, the maximum 8-hour daily ozone and day-prior ozone was highly correlated (correlation coefficient: 0.59). Ozone at 1 days' lag was weakly to moderately associated with the daily maximum humidex value at 0, 1, 2, and 3 days' lag, and PM_{10} (correlation coefficients ranging from 0.09 to 0.59). Similar patterns were observed for Clark County and Spokane County.

Main Effects Analyses

Consistently, there was evidence that ozone exposure was associated with respiratory-related hospital admissions at 3 days' lag. For instance, among Clark county residents, a 10 ppb increase in ozone at 3 days' lag was associated with 4% increase in risk for respiratory-related hospital admissions (adjusted for date [spline], day of week, ozone at 0–2 days' lag, humidex at 0–3 days' lag, and PM_{10} at 0 days' lag; RR=1.04, 95% CI: 1.02, 1.07). There was limited evidence that ozone at 0–2 days' lag was associated with respiratory-related hospital admissions. Similar patterns were observed for Spokane and King County (see Tables 4 and 5).

Effect Modification

The results of stratified analyses also demonstrated some statistically significant associations by age, sex, or health insurance status but the results were not consistent across counties. Among the two oldest age groups (64–84 years and 85+ years), the stratified results indicate an increase in risk for respiratory-related hospital admissions at 3 days' lag in Clark County (Table 3; adjusted RR for adults, aged 65–84 years=1.05; 95% CI: 1.02, 1.09; adjusted RR for adults, aged 85+ years=1.09, 95% CI: 1.02, 1.17) and King County (Table 5; adjusted RR for adults, aged 65–84 years=1.03; 95% CI: 1.01, 1.05; adjusted RR for adults, aged 85+ years=1.05, 95% CI: 1.02, 1.08). In Clark County, ozone at 3 days' lag was associated with an increase in risk for respiratory-related hospital admissions among children, aged 0–4 years (Table 3; adjusted RR=1.11, 95% CI: 1.02, 1.22). In Spokane County, ozone at 3 days' lag was associated with an increase in risk for respiratory-related hospital admissions among adults, aged 45–64 years (Table 4; adjusted RR=1.05, 95% CI: 1.01, 1.10). There were some indications that ozone at 2 days' lag was associated with a decrease in risk for respiratory-related hospital admissions among children, aged 5–14 years, in Clark County (Table 3; adjusted RR=0.82, 95% CI: 0.70, 0.96) and in King County (Table 5; adjusted RR=0.94, 95% CI: 0.89, 0.99). No evidence suggesting an increase in risk among adults, aged 15–44 years, was observed.

There were also some indications of effect modification by sex and health insurance, but the results were also inconsistent. For instance, there was evidence for higher risk for respiratory-related hospital admissions among males but not females in Clark County (Table 3; adjusted RR=1.04, 95% CI: 1.01, 1.07) and King County (Table 4; adjusted RR=1.03, 95% CI: 1.01, 1.04) whereas there was evidence for higher risk for respiratory-related

hospital admissions among females in Spokane County (Table 4; adjusted RR=1.04, 95% CI: 1.01, 1.07). In Clark County there was an increased risk for respiratory-related hospital admissions among residents who held Medicare, HMO/private, or other types of insurance (Table 3) and in King County there was an increased risk for respiratory-related hospital admissions among residents who held Medicare (Table 5). Conversely, in Spokane County, there was an increased risk for respiratory-related hospital admissions among residents who held Health Care Services Contractor insurance (Table 4). Finally, the results indicate a decrease in risk for respiratory-related hospital admissions for HMO/private, Medicaid, and Labor & Industries insurance.

Sensitivity Analyses

In the collapsed age group analyses of children, aged 0–14 years, and adults, aged 65+ years, we observed both significant increases and decreases in risk for age-specific hospital admissions. For instance, among adults, aged 65+ years, there was some evidence of an increase in risk for age-specific hospital admissions at 1 days' lag in Spokane County (Table 4; adjusted RR=1.08; 95% CI: 1.02, 1.15) and King County (Table 5; adjusted RR=1.05; 95% CI: 1.01, 1.09) and there was an increase in risk for age-specific hospital admissions at 3 day's lag in Clark County (Table 3; adjusted RR= 1.14, 95% CI: 1.04, 1.25) and King County (Table 5; adjusted RR=1.05; 95% CI: 1.01, 1.10).

The age-specific results for children, aged 0–14 years, conflicted across the counties. Among children, aged 0–14 years, there was some evidence of an increase in risk for respiratory-related hospital admissions at 3 days' lag in Clark County (Table 3; adjusted RR=1.08; 95% CI: 1.02, 1.15) and 1 days' lag in Spokane County (Table 4; adjusted RR=1.08, 95% CI: 1.02, 1.15). Conversely, the age-specific results for King County indicate a decrease in risk for respiratory-related hospital admissions among children, aged 0–14 years, at 0 and 2 days' lag (adjusted RR for 0 days' lag= 0.94, 95% CI: 0.92, 0.97; adjusted RR for 2 days' lag=0.96, 95% CI: 0.93, 0.99).

Discussion

Evidence is building that low-level or short-term exposure to ozone contributes to increased risk for respiratory-related hospital admissions.[6–8] In support of this hypothesis, our results indicate that exposure to ozone increases risk for respiratory-related hospital admissions in a setting with low to moderate levels of ambient ozone. Our results also revealed some sex- and health insurance status-related associations. The age-stratified results are consistent with the growing literature demonstrating increased health risk among children and older adults. In addition, observations related to hospital admissions covered by health insurance status support future more specific hypothesis testing around socio-demographic exposure to ozone.

Ozone is a common air pollutant that has been shown to adversely affect respiratory health.[11] Our results support the numerous studies reporting an increase in risk for respiratory-related hospital admissions following ozone exposure.[11,15,21,22] In general, we observed the largest effects at 3 days' lag. This pattern is consistent with a meta-analysis of the associations between ozone exposure and hospital admissions for respiratory

conditions,[21] in addition to other research conducted in the region.[23,24] The longer lag associations could be due to a delay in the physiological response (e.g. immune suppression, inflammation) between exposure to ozone and actual day of hospital admission.[25] Additionally, the observed delay in hospital admissions may be a result of chronic, low-level exposure to summertime ozone.[26]

Our study adds to the limited body of evidence investigating the age-stratified associations between ozone and respiratory-related hospital admissions. Consistent with the published literature,[11,21,22] our results indicate higher risk estimates among the oldest age groups and Medicare recipients. However, the risk estimates in children, aged 0–4 years, were weaker than what has been previously reported.[6,24] Furthermore, and contrary to what was hypothesized, we observed a decrease in risk for respiratory-related hospital admissions among children, aged 5–14 years. There are several potential explanations for these discrepancies. First, our study may be limited by exposure misclassification, which may have biased the effect estimates towards the null. Previous studies were conducted in smaller areas with finer resolution (e.g. Washington D.C. and Seattle) whereas our study examined these associations across a larger area (e.g. King County, which covers 2,307 square miles). Additionally, ozone is a highly reactive, unstable air pollutant (unlike PM) and therefore may not be uniformly distributed over the entire county.[27] Second, the weaker associations observed in the present study could be a result of the low levels of ambient ozone in the study region.[21] Third, these previous studies evaluated the impact of ozone on specific conditions (asthma) whereas our study evaluated the impact of ozone on a variety of respiratory conditions among children (asthma, pneumonia, croup, and bronchitis/bronchiolitis).

There was limited evidence in our study that sex or health insurance status may influence sensitivity to ozone. Health insurance status may have been examined as a proxy for age (e.g. Medicare representing more older adults), socioeconomic status (e.g. Medicaid representing more economically disadvantaged), or potential occupational exposures (e.g. Labor & Industries representing more outdoor workers). Although we observed some indications for increased susceptibility among Medicare and Medicaid recipients, the effect estimates were small and were not consistent across counties. Labor & Industries health insurance status was associated with increased risk for respiratory-related hospital admissions at 2 days' lag for both Spokane and King Counties, but these effects were not statistically significant., Similarly, we observed sex-stratified effect estimates that were contradictory across counties. Further research is needed to examine potential differences in the association between ozone and respiratory-related hospital admissions by sex or health insurance status.

A limitation of the present study is the observational nature of the study design, which does not allow for establishing the causality of these relationships. Due to the nature of the hospital admissions data, we were unable to evaluate confounding due to other important factors related to the ozone exposure and respiratory conditions, such as socio-demographic variables (e.g. race/ethnicity, education level, family income), features of the microenvironments (e.g. rate of air exchange, ventilation in indoor environments),[28] or occupational exposures (e.g. dust, fungi, chemicals).[29] Multiple comparisons could have

resulted in some of the significant associations. We did not make any adjustments for multiple comparisons because these adjustments introduce more error into the interpretation of the results.[30] Furthermore, as our results are consistent with previous studies, we interpret these results as support for the hypothesis that exposure to ozone is associated with hospital admissions for respiratory illness.

An important advantage of this study was the ability to examine these associations across three climatologically, topographically, and demographically diverse counties in Washington State.[31] Another strength of this study is the ability to adjust for likely high-impact confounders such as temperature and PM.[32,33]

Implications

Counties in Washington experience lower ambient ozone concentrations relative to counties in other states. Based on the American Lung Association's 2015 State of the Air report, Clark and Spokane County are ranked among the cleanest counties in the U.S. for having zero days that exceeded the National Ambient Air Quality Standards (NAAQS) for ozone between 2011–2013. During the same time period, King County experienced two days that exceeded the NAAQS guidelines and received a 'B' grade; by comparison, San Bernardino County, CA (a county that is similar in size and population to King County) experienced 314 days that exceeded the NAAQS guidelines and received an 'F' grade. We observed that, even at relatively low levels, ozone exposure increases the risk for hospital admissions for respiratory illness; these findings are corroborated by previous epidemiologic research examining a similar hypothesis using data from Metropolitan King County.[34] Furthermore, as it is anticipated that rising temperatures will increase the formation of tropospheric ozone, susceptible populations (children, older adults, outdoor laborers) may be at continuing increased risks to the negative health impacts of ozone.[35]

Acknowledgments

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Table 1

Demographic characteristics for respiratory-related hospital admissions within King, Clark, and Spokane County

	King County	Clark County	Spokane County
Total Respiratory Visits	**61,705**	**8,932**	**21,876**
Sex (%)			
Female	50.7	46.8	48.9
Age Categories (%)			
0–4 years	11.1	5.4	11.8
5–14 years	5.0	2.4	4.1
15–44 years	14.2	12.1	13.9
45–64 years	20.4	23.1	20.8
65–84 years	37.7	44.4	39.5
85+ years	11.7	12.6	9.9
Health Insurance Provider (%)			
Medicare	45.1	53.1	54.7
HMO/Private	25.5	25.9	13.0
Medicaid	15.6	13.9	18.2
Health Care Services Contractor	8.3	3.5	10.6
Self-pay	3.9	2.3	1.6
Other	1.2	1.0	1.5
Labor & Industries	0.2	0.3	0.4
Diagnostic Category (%)			
Pneumonia and influenza	34.6	41.2	37.4
COPD and COPD-related conditions[a]	30.6	29.7	28.6
Other respiratory diseases	17.9	17.5	18.3
Lung disease due to external agents	9.1	6.0	7.4
Acute infections of the upper respiratory tract	5.5	4.3	6.9
Other diseases of the upper respiratory tract	2.3	1.2	1.3
Admissions among children, ages 0–14 years	**9,928**	**695**	**3,481**
Childhood specific codes (%)[b]			
Asthma	66.2	46.3	35.0
Pneumonia	18.9	36.7	36.7
Croup	7.5	6.4	6.7
Bronchitis/Bronchiolitis	7.2	10.5	21.5
Admissions for older adults, ages 65+ years	**30,434**	**5,095**	**10,801**
Older adult specific codes (%)[b]			
Pneumonia	63.5	64.1	63.1
Chronic obstructive pulmonary diseases	33.9	33.2	35.2
Bronchitis	2.5	2.7	1.4
Influenza	0.1	0.0	0.1

Abbreviations: COPD, chronic pulmonary obstructive disease; HMO, health maintenance organization

[a]Includes asthma, emphysema, and chronic bronchitis

[b]Percentages for age subsets reflect population for the specific diagnostic set

Table 2

Eight-hour daily maximum ozone values (ppb) and 24-hr average PM_{10} (μg/m3) by county, 1990 – 2006.

	Clark	Spokane	King
Ozone			
Days Observed	2,601	2,552	2,601
Mean (SD)	41.4 (20.0)	45.8 (10.0)	34.8 (13.3)
Minimum	7.2	12.4	6.3
1st Quartile	28.4	38.8	25.3
Median	36.9	45.4	33.1
3rd Quartile	48.6	52.5	42.3
Maximum	160.9	77.4	106.5
PM_{10}			
Days Observed	565	2,658	1,644
Mean (SD)	17.5 (7.1)	28.6 (24.7)	22.1 (9.7)
Minimum	4.2	1.0	5.3
1st Quartile	14.0	18.0	14.8
Median	17.2	26.0	19.0
3rd Quartile	21.3	35.8	24.3
Maximum	58.0	803	65.0

Table 3

Adjusted[a] relative risks and 95% confidence intervals for respiratory-related hospital admissions by 10 ppb increases in ozone: Main effects estimates and estimates stratified by sex, age, and health insurance, Clark County

	0 days' lag RR (95% CI)	1 days' lag RR (95% CI)	2 days' lag RR (95% CI)	3 days' lag RR (95% CI)
Main Effect	0.99 (0.98, 1.01)	0.98 (0.96, 1.00)	0.99 (0.97, 1.02)	**1.04 (1.02, 1.07)**
Stratified Estimates				
Sex				
Females	0.99 (0.96, 1.02)	1.00 (0.97, 1.04)	1.01 (0.97, 1.05)	**1.04 (1.00, 1.07)**
Males	1.00 (0.98, 1.03)	0.99 (0.96, 1.03)	1.00 (0.96, 1.03)	**1.08 (1.01, 1.15)**
Age Categories				
0–4 years	0.98 (0.90, 1.06)	1.06 (0.95, 1.18)	0.97 (0.87, 1.08)	**1.11 (1.02, 1.22)**
5–14 years	1.00 (0.89, 1.12)	1.02 (0.87, 1.18)	**0.82 (0.70, 0.96)**	1.14 (0.99, 1.31)
15–44 years	1.02 (0.96, 1.07)	0.94 (0.88, 1.01)	1.01 (0.94, 1.09)	1.04 (0.97, 1.11)
45–64 years	1.00 (0.96, 1.04)	0.99 (0.94, 1.04)	1.03 (0.97, 1.09)	1.03 (0.99, 1.09)
65–84 years	1.00 (0.97, 1.03)	1.00 (0.97, 1.04)	1.00 (0.96, 1.04)	**1.05 (1.02, 1.09)**
85+ years	0.96 (0.84, 1.09)	1.01 (0.94, 1.09)	1.00 (0.92, 1.08)	**1.09 (1.02, 1.17)**
Health Insurance Provider				
Medicare	1.00 (0.97, 1.02)	1.00 (0.97, 1.03)	1.00 (0.97, 1.04)	**1.05 (1.02, 1.09)**
HMO/Private	0.99 (0.95, 1.03)	0.97 (0.92, 1.02)	1.01 (0.96, 1.07)	**1.08 (1.03, 1.14)**
Medicaid	1.00 (0.95, 1.05)	1.02 (0.96, 1.09)	0.98 (0.92, 1.05)	1.05 (0.99, 1.11)
Health Care Services Contractor	0.96 (0.88, 1.05)	1.00 (0.88, 1.12)	0.98 (0.86, 1.12)	1.10 (0.99, 1.23)
Self-pay	1.09 (0.95, 1.25)	1.03 (0.86, 1.24)	0.98 (0.80, 1.19)	0.97 (0.81, 1.15)
Other	0.96 (0.84, 1.09)	1.01 (0.94, 1.09)	1.00 (0.92, 1.08)	**1.09 (1.02, 1.17)**
Labor and Industries	–	–	–	–
Sensitivity Analyses				
Age-Specific Admissions				
Children, ages 0–14 years	0.97 (0.91, 1.04)	1.06 (0.97, 1.16)	0.93 (0.85, 1.03)	**1.11 (1.01, 1.21)**
Adults, ages 65+ years	0.93 (0.87, 1.00)	1.02 (0.94, 1.11)	0.98 (0.89, 1.07)	**1.14 (1.04, 1.25)**

Abbreviations: CI, confidence interval; HMO, health maintenance organization; ppb, parts per billion; RR, relative risk

[a]Adjusted for time trend, day of week, maximum daily humidex (lags 0 – 3) and 24-hr average PM_{10}.

Table 4

Adjusted[a] relative risks and 95% confidence intervals for respiratory-related hospital admissions by 10 ppb increases in ozone: Main effects estimates and estimates stratified by sex, age, and health insurance, Spokane County

	0 days' lag RR (95% CI)	1 days' lag RR (95% CI)	2 days' lag RR (95% CI)	3 days' lag RR (95% CI)
Main Effect	1.01 (0.97, 1.05)	1.02 (1.00, 1.05)	1.01 (0.99, 1.04)	**1.03 (1.01, 1.05)**
Stratified Estimates				
Sex				
Females	1.03 (1.00, 1.06)	1.02 (0.99, 1.05)	1.02 (0.99, 1.06)	**1.04 (1.01 1.07)**
Males	1.03 (1.00, 1.06)	1.03 (1.00, 1.06)	1.00 (0.97, 1.03)	1.02 (0.99, 1.05)
Age Categories				
0–4 years	1.02 (0.97, 1.09)	1.09 (1.02, 1.17)	1.04 (0.98, 1.11)	1.06 (0.98, 1.11)
5–14 years	1.07 (0.97, 1.19)	1.06 (0.95, 1.19)	0.92 (0.82, 1.03)	1.00 (0.90, 1.11)
15–44 years	1.00 (0.95, 1.05)	1.01 (0.95, 1.07)	1.00 (0.94, 1.06)	1.03 (0.98, 1.09)
45–64 years	0.97 (0.93, 1.02)	1.01 (0.96, 1.06)	1.03 (0.98, 1.08)	**1.05 (1.01, 1.10)**
65–84 years	1.01 (0.98, 1.04)	1.03 (0.99, 1.06)	1.01 (0.98, 1.05)	1.02 (0.98, 1.05)
85+ years	1.03 (0.96, 1.09)	0.99 (0.92, 1.06)	1.00 (0.93, 1.07)	1.01 (0.95, 1.08)
Health Insurance Provider				
Medicare	1.00 (0.98, 1.03)	1.01 (0.98, 1.04)	1.02 (0.99, 1.05)	1.02 (0.99, 1.05)
HMO/Private	1.05 (0.99, 1.11)	1.05 (0.99, 1.12)	0.99 (0.93, 1.05)	1.03 (0.97, 1.09)
Medicaid	0.98 (0.94, 1.03)	1.06 (1.00, 1.11)	1.03 (0.98, 1.09)	1.03 (0.98, 1.08)
Health Care Services Contractor	1.03 (0.97, 1.10)	0.99 (0.92, 1.06)	1.00 (0.93, 1.07)	**1.07 (1.01, 1.14)**
Self-pay	0.94 (0.80, 1.10)	1.19 (0.99, 1.41)	0.95 (0.80, 1.14)	0.96 (0.82, 1.14)
Other	0.93 (0.79, 1.10)	0.96 (0.80, 1.16)	0.99 (0.82, 1.20)	1.13 (0.95, 1.34)
Labor and Industries	0.84 (0.61, 1.15)	1.04 (0.74, 1.47)	1.42 (0.99, 2.04)	1.18 (0.85, 1.63)
Sensitivity Analyses				
Age-Specific Admissions				
Children, ages 0–14 years	1.03 (0.98, 1.09)	**1.08 (1.02, 1.15)**	1.00 (0.93, 1.06)	1.06 (1.00, 1.12)
Adults, ages 65+ years	1.03 (0.95, 1.11)	0.97 (0.89, 1.05)	0.97 (0.89, 1.06)	1.06 (0.99, 1.15)

Abbreviations: CI, confidence interval; HMO, health maintenance organization; ppb, parts per billion; RR, relative risk

[a] Adjusted for time trend, day of week, maximum daily humidex (lags 0 – 3) and 24-hr average PM_{10}.

Table 5

Adjusted[a] relative risks and 95% confidence intervals for respiratory-related hospital admissions by 10 ppb increases in ozone: Main effects estimated and estimates stratified by sex, age, and health insurance, King County

	0 days' lag RR (95% CI)	1 days' lag RR (95% CI)	2 days' lag RR (95% CI)	3 days' lag RR (95% CI)
Main Effect	0.99 (0.99, 1.00)	1.01 (1.00, 1.02)	1.00 (0.99, 1.02)	**1.02 (1.01, 1.03)**
Stratified Estimates				
Sex				
Females	1.00 (0.98, 1.01)	1.01 (1.00, 1.03)	1.01 (0.99, 1.02)	1.02 (1.00, 1.03)
Males	0.99 (0.98, 1.01)	1.01 (1.00, 1.03)	1.00 (0.98, 1.02)	**1.03 (1.01, 1.04)**
Age Categories				
0–4 years	0.96 (0.93, 1.00)	1.04 (1.01, 1.08)	0.99 (0.95, 1.02)	0.98 (0.95, 1.01)
5–14 years	**0.93 (0.89, 0.97)**	0.98 (0.94, 1.03)	**0.94 (0.89, 0.99)**	1.00 (0.96, 1.05)
15–44 years	0.99 (0.96, 1.01)	1.01 (0.98, 1.04)	0.99 (0.96, 1.02)	1.02 (0.99, 1.05)
45–64 years	1.00 (0.98, 1.02)	1.00 (0.97, 1.02)	1.03 (1.00, 1.06)	1.02 (1.00, 1.05)
65–84 years	1.01 (0.99, 1.02)	1.02 (1.00, 1.03)	1.02 (0.84, 1.23)	**1.03 (1.01, 1.05)**
85+ years	1.03 (1.00, 1.06)	1.03 (1.00, 1.07)	0.97 (0.94, 1.01)	**1.05 (1.02, 1.08)**
Health Insurance Provider				
Medicare	1.02 (1.00, 1.03)	1.01 (1.00, 1.03)	1.01 (1.00, 1.03)	**1.03 (1.01, 1.05)**
HMO/Private	**0.98 (0.96, 0.99)**	1.01 (0.99, 1.03)	0.99 (0.97, 1.01)	1.01 (0.99, 1.03)
Medicaid	**0.97 (0.95, 0.99)**	1.03 (1.00, 1.06)	1.00 (0.97, 1.03)	1.02 (0.99, 1.05)
Health Care Services Contractor	1.00 (0.97, 1.03)	1.00 (0.96, 1.04)	1.00 (0.96, 1.04)	1.03 (0.99, 1.07)
Self-pay	0.98 (0.94, 1.03)	0.98 (0.93, 1.03)	1.02 (0.96, 1.08)	1.02 (0.94, 1.07)
Other	0.99 (0.91, 1.08)	1.08 (0.98, 1.20)	0.97 (0.87, 1.07)	1.02 (0.92, 1.12)
Labor and Industries	**0.83 (0.69, 0.99)**	1.08 (0.87, 1.33)	1.20 (0.94, 1.52)	0.97 (0.78, 1.21)
Sensitivity Analyses				
Age-Specific Admissions				
Children, ages 0–14 years	**0.94 (0.92, 0.97)**	1.03 (1.00, 1.06)	**0.96 (0.93, 0.99)**	0.98 (0.96, 1.01)
Adults, ages 65+ years	1.03 (1.00, 1.07)	**1.05 (1.01, 1.09)**	0.97 (0.93, 1.01)	**1.05 (1.01, 1.10)**

Abbreviations: CI, confidence interval; HMO, health maintenance organization; ppb, parts per billion; RR, relative risk

[a] Adjusted for time trend, day of week, maximum daily humidex (lags 0 – 3) and 24-hr average PM_{10}.