Association between outdoor ozone and compensated acute respiratory diseases among workers in Quebec (Canada)

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Abstract: Respiratory effects of ozone in the workplace have not been extensively studied. Our aim was to explore the relationship between daily average ozone levels and compensated acute respiratory problems among workers in Quebec between 2003 and 2010 using a time-stratified case-crossover design. Health data came from the Workers' Compensation Board. Daily concentrations of ozone were estimated using a spatiotemporal model. Conditional logistic regressions, with and without adjustment for temperature, were used to estimate odds ratios (ORs, per 1 ppb increase of ozone), and lag effects were assessed. Relationships with respiratory compensations in all industrial sectors were essentially null. Positive non-statistically significant associations were observed for outdoor sectors, and decreased after controlling for temperature (ORs of 0.98; 1.01 and 1.05 at Lags 0, 1 and 2 respectively). Considering the predicted increase of air pollutant concentrations in the context of climate change, closer investigation should be carried out on outdoor workers.

Key words: Air pollution, Compensation data, Ozone, Respiratory diseases, Workers

Ozone is a major air pollutant responsible for acute and chronic damages to the respiratory system[1], and there is increasing evidence suggesting that outdoor workers are at risk of ozone-related respiratory effects[2]. In the context of climate change, predicted increases in surface temperature and greenhouse gases emissions could result in the increase of background surface ozone[3]. Workers could be exposed to higher concentrations of this pollutant in the future, especially on warm days when ozone levels are known to be high[4]. Our aim was to explore the relationship between daily average ozone levels and compensated acute respiratory diseases among workers in Quebec (Canada).

Compensation data came from the Workers' Compensation Board (WCB) of Quebec, the exclusive provider of compensations for employment injuries and illnesses for persons who do remunerated work for an employer in Quebec. The period of study was from May 1st to September 30th of each year between 2003 and 2010. These months cover the period when outdoor ozone levels are higher, as concentrations during the winter are almost null in Quebec[5], while the years of study were chosen according to availability of data. In the WCB database, all

injuries coded for Respiratory system diseases according to the Canadian Standards Association (Standard Z795) were retained, except those resulting from stings of wasps, bees and hornets, and from the ingestion of substances. No claim was compensated more than once for the same illness within 31 d.

The study area was restricted to the territory where daily ozone levels were available (Fig. 1). Daily average levels of ozone (9–17 h) were obtained from a Bayesian Maximum Entropy spatiotemporal model, developed over Quebec (R^2 = 0.653; Root mean square error = 7.06 ppb). Details on the model can be found in Adam-Poupart *et al*[5].

We assessed the relation between daily ozone levels and compensated acute respiratory problems using a case-crossover design[6]. In this design, temporal trends are adjusted for by selecting control days for each day in which at least one acute respiratory problem occurred (case day). This design partially controls for potential confounders by making within-subject (i.e. workers) comparisons. Using a time-stratified approach in which the study period is divided into monthly strata, we selected as control days for each case day the same days of the other weeks in the same month. Thus, if a respiratory problem occurred on Tuesday 10 March 2009, the selected control days were other Tuesdays of the same month (3, 17, 24 and 31 March 2009). Daily mean ozone concentrations were estimated for the six-digit postal code of each employer establishment's location on case and control days.

Conditional logistic regressions were used to compare daily mean ozone levels for case days with their matched control days. Case days with less than three control days were discarded. Odds ratios (ORs) and their 95% confidence intervals (CIs) were expressed per 1 ppb increase of ozone levels. Models were adjusted for daily mean temperature (9–17 h), estimated from hourly meteorological data available from the Environment Canada Data Access Integration Team (http://loki.qc.ec.gc.ca/DAI/DAI-e.html). Additionally, the statistical interaction between ozone and temperature was verified by adding a product term to the model.

Analyses were conducted for all industrial sectors and then restricted to industries with mostly outside work (i.e. agriculture, construction, fishing/hunting/trapping, forestry/logging/supporting activities, mining/quarrying/oil/gas extraction, and transport/warehousing). We assessed possible time-lag effects by looking at the association between compensations and ozone levels of the current day (lag 0), and of the two previous days (lag 1 and lag 2). The cumulative effect of two-day (mean of lags 0–1) and three-day (mean of lags 0–1–2) moving averages of daily levels
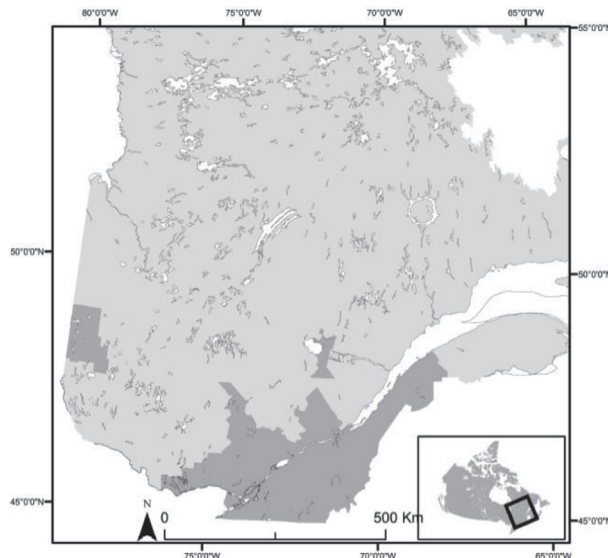

Fig. 1. Geographical location the territory (dark grey) where daily ozone levels were available in Quebec (Canada).

of ozone was also estimated. All analyses were conducted with Stata version 12.1.

Overall, 328 respiratory diseases were compensated in Quebec from 2003 to 2010 (May–Sept). Of these compensations, 252 were retained for analysis, as they occurred in areas for which we could estimate ozone concentrations on case and control days. Only 26 compensations occurred in industrial sectors with mostly outdoor work. The number of compensations per type of acute respiratory problem and industrial sector is presented in Table 1. Estimates of daily average concentrations of ozone on case days retained for the analysis ranged from 9.2 to 59.8 ppb (mean of 28.1 ppb) and daily mean temperature from 5.3 to 30.5 °C (mean of 19.2 °C). Estimates of daily average concentrations of ozone on control days ranged from 6.9 to 61.4 ppb (mean of 28.0 ppb) and daily mean temperature from 2.9 to 31.8 °C (mean of 19.2 °C).

Associations between ozone estimates and compensated acute respiratory problems are detailed in Table 2. Crude relationships with respiratory compensations in all industrial sectors were essentially null, the adjustment for temperature increased the effect of ozone and the interactions between daily ozone and daily mean temperature were significant at almost all lags and moving averages. In sectors with mostly outdoor work, crude associations for compensations were all positive (all lags and moving averages); however a large statistical variability was noted and adjusting for temperature reduced the effect of ozone. For these sectors, no statistical interaction was found between

Table 1.   Number of compensations per type of respiratory problems and industrial sectors (Quebec, May–September 2003–2010)

	Number of compensations	(%)
Natures		
Extrinsic asthma	70	27.8
Reactive airways dysfunction syndrome	28	11.1
Acute respiratory infections	25	9.9
Other respiratory system diseases. NEC[a]	23	9.1
Influenza	15	6.0
Bronchitis	13	5.2
Respiratory system diseases. UNS[a]	10	4.0
Pneumonia. influenza. NEC[a]	10	4.0
Chronic obstructive pulmonary diseases and allied conditions. NEC[a]	9	3.6
Pneumonitis. NEC[a]	8	3.2
Allergic rhinitis	7	2.8
Pneumonia	6	2.4
Chronic conditions of upper respiratory tract	5	2.0
Diseases of upper respiratory tract. UNS[a]	3	1.2
diseases of upper respiratory tract. NEC[a]	3	1.2
Asbestosis	3	1.2
Pulmonary edema	3	1.9
Chronic obstructive pulmonary diseases and allied conditions. UNS[a]	2	0.8
Chronic obstructive lung disease	2	0.8
Pneumonia. influenza. UNS[a]	1	0.4
Legionnaires' disease	1	0.4
Extrinsic allergic alveolitis and pneumonitis Includes: farmers' lung. bagassosis	1	0.4
Silicosis	1	0.4
Berylliosis	1	0.2
Byssinosis. mill fever	1	0.4
Pneumonopathy. NEC[a]	1	0.4
Pulmonary fibrosis. NEC[a]	1	0.4
Industrial Sectors		
Manufacturing	78	31.0
Health care and social assistance	62	24.6
Wholesale and Retail trade	26	10.3
Construction	11	4.4
Educational services	11	4.4
Waste management and remediation services; Management of companies and enterprises; Administrative and support services	10	4.0
Unclassified	10	4.0
Public administration	8	3.2
Agriculture	7	2.8
Transportation and warehousing	7	2.8
Professional. scientific and technical services	5	2.0
Accommodation and food services	5	2.0
Other services including Repair and maintenance (except public administration)	4	1.6
Finance and insurance	3	1.2
Utilities	2	0.8
Information and cultural industries; Arts. entertainment and recreation	2	0.8
Mining. quarrying. oil and gas extraction	1	0.4
Forestry. logging and supporting activities	0	0.0
Fishing. hunting and trapping	0	0.0

[a]UNS: Unspecified; NEC; Not elsewhere classified

Table 2. Associations between ozone estimates and compensated acute respiratory problems among workers, for each 1 ppb increment of average ozone levels, in Quebec, May–September 2003–2010[a]

Timing of ozone exposure	All compensations (2003–2010)			Compensations for sectors with mostly outdoor work (2003–2010)[b]		
	Days with compensations (n)	OR per 1 ppb increase in daily average ozone concentration (95%CI)	Interaction between ozone and temperature	Days with compensations (n)	OR per 1 ppb increase in daily average ozone concentration (95%CI)	Interaction between ozone and temperature
		Not adjusted	Adjusted [c]	*p* value		Not adjusted	Adjusted [c]	*p* value
Lag 0	252	1.01 (0.98; 1.03)	1.01 (0.98; 1.05)	<0.01	26	1.02 (0.95; 1.10)	0.98 (0.88; 1.09)	0.75
Lag 1	250	1.00 (0.97; 1.02)	1.01 (0.98; 1.05)	0.05	26	1.04 (0.96; 1.12)	1.01 (0.91; 1.12)	0.73
Lag 2	243	1.00 (0.97; 1.03)	1.01 (0.98; 1.05)	0.40	23	1.06 (0.98; 1.13)	1.05 (0.93; 1.18)	0.66
Lags 0–1[d]	244	1.00 (0.98; 1.03)	1.01 (0.98; 1.05)	<0.01	25	1.03 (0.95; 1.12)	0.98 (0.87; 1.10)	0.70
Lags 0–2[e]	230	1.00 (0.97; 1.03)	1.01 (0.97; 1.06)	0.02	22	1.05 (0.95; 1.16)	0.98 (0.84; 1.15)	0.24

[a] Compensations occurring in areas for which we could estimate ozone concentrations with the model on case and control days, and for which we had 3 or 4 control days per case day (106 case days out of 358 were excluded because they had less than 3 controls days). Missing ozone values on control days are spatiotemporal moment (postal code-days) that were not estimated with the BME model, due to lack of data. [b]Sectors with mostly outdoor work: agriculture, construction, fishing/hunting/trapping, forestry/logging/supporting activities, mining/quarrying/oil and gas extraction, transport/warehousing. [c]Ajusted for mean daily temperature, evaluated on the same day as ozone estimates. [d] Two-day lag average. [e] Three-day lag average

ozone and temperature (*p*-values varied from 0.24 to 0.75). An analysis was also performed after excluding the 28 cases of reactive airways dysfunction syndrome (RADS) as these often happen following accidental exposure to irritants, but the results were essentially unchanged (adjusted ORs for all industries varied across lags from 0.99 to 1.01; for sectors with mostly outdoor work, it varied from 0.93 to 1.02; data not presented).

The positive trend noted only for outdoor workers could be attributed to higher exposure of outdoor workers to ambient air pollution compared to indoor workers. Outdoor workers are classified as one of the most common categories of people at increased risk of ozone-related respiratory health effects due to the duration of exposure[2]. Moreover, some occupations in these sectors are physically demanding (i.e. roofers) and workers in these occupations could possibly inhale higher doses of pollutants because of the increase in minute ventilation associated with physical activity[4]. Delayed respiratory effect of ozone on outdoor workers, which was previously reported in mail carriers in Taiwan[7] and in berry pickers in Canada[8, 9], is also suggested by the positive trend of associations from lag 0 to lag 2 noted for outdoor workers.

This study presents several limitations that could potentially explain the inconclusive results. Firstly, the statistical variability observed for the crude positive associations between ozone levels and respiratory compensations for outdoor workers may be explained, at least partially, by the small number of cases (n=26 case days). Secondly, we analyzed compensation data which is known to reflect only part of actual work-related injuries and illnesses[10]. It is likely that our analysis underestimates the actual risks, as several industrial sectors with outdoor activities are well known for underreporting injuries, such as agriculture, forestry, fishing and construction[11]. Between 2003 and 2010, 17 compensations occurred in these sectors compared to 26 for sectors with mostly outdoor work. Moreover, the lack of precision of both the health indicators and the exposure assessment methods could have resulted in the dilution of the ozone effect and be responsible for the inconclusive results. In the few studies where statistically significant associations between ozone and respiratory health effects were observed among workers, lung functions were evaluated more precisely using spirometry[7–9, 12] or the exposure was assessed individually with portable sampling devices[13].

Lastly, the adjustment for temperature had varying influences on the effect of ozone; it barely influenced the magnitude of the association between ozone levels and respiratory compensations for all industrial sectors, but reduced the association for sectors with mostly outdoor work. Therefore, it is unclear if the observed trends for outdoor workers are due to ozone levels, to high temperatures or to other unmeasured parameters that are associated with them.

Moreover, the statistical interaction between daily ozone and daily mean temperature was erratic. In the literature, the respiratory effect of a co-exposure to heat and ozone has never been explored in the workplace and conclusions on the role of ozone in health studies of heat exposure in the general population are inconsistent[14]. In a recent review of the scientific epidemiological evidences on the respiratory effects of climate events (such as heat) combined to air quality (such as ozone) in the context of climate change, De Sario *et al.*[15] reported that the temperature-air pollution interactions can not be easily considered in temperature or air pollution respiratory studies, because the true magnitude of the association may be underrestimated.

However, several studies provided consistent evidence of a synergy between ozone and heat exposure, and from a toxicological perspective, interactions could occur during co-exposure: heat triggers a series of compensatory physiological responses, such as respiratory rate increases, which could simultaneously increase the volume of inhaled air and the ozone dose reaching the respiratory system[15].

In conclusion, although the present study needs replication, its results nonetheless suggest a possible association between exposure to ozone and delayed acute respiratory problems among outdoor workers in Quebec and present some evidence of an interaction between ozone concentrations and temperature. Considering the predicted increase of ozone concentrations in the context of climate change[3], closer investigation should be carried out on the potential respiratory impact of this pollutant among outdoor workers. The co-exposure with other air pollutants that may have acute respiratory effects, such as fine particulates and nitrogen oxides[7, 13] should also be assessed.

Acknowledgements

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