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Exposure to industrial air pollutant emissions and lung function in children: Canadian Health Measures Survey, 2007 to 2011

by Suzy L. Wong, Allan L. Coates and Teresa To

Abstract

Background: Long-term exposure to ambient air pollution has been associated with adverse effects on children's lung function. Few studies have examined lung function in relation to industrial emissions of air pollutants.

Data and methods: This cross-sectional study was based on 2,833 respondents aged 6 to 18 for whom spirometry data were collected by the Canadian Health Measures Survey, 2007 to 2011. The weighted sum of industrial air emissions of nitrogen oxides (NO_x) and fine particulate matter ($PM_{2.5}$) within 25 km of the respondent's residence was derived using National Pollutant Release Inventory data. Multivariate linear regression was used to examine the relationship between NO_x and $PM_{2.5}$ emissions and forced vital capacity (FVC), the forced expiratory volume in 1 sec (FEV_1), and the ratio of the two (FEV_1/FVC).

Results: Industrial air emissions of NO_x were not significantly associated with lung function among males or females. Emissions of $PM_{2.5}$ were negatively associated with FEV_1 and FEV_1/FVC, but not FVC, among males. $PM_{2.5}$ was not significantly related to lung function among females.

Interpretation: The associations that emerged between lung function and industrial emissions of $PM_{2.5}$ among males were consistent with airway obstruction. Further research is warranted to investigate the gender differences observed in this study.

Keywords: Ambient air pollution, particulate matter, nitrogen dioxide, National Pollutant Release Inventory, outdoor air pollution

Lung function is an objective measure of respiratory health and a predictor of cardiorespiratory morbidity and mortality.[1] Long-term exposure to ambient air pollution has been associated with adverse effects on children's lung function.[2-4] These pollutants include, but are not limited to, nitrogen dioxide (NO_2) and fine (less than 25 micrometres in diameter) particulate matter ($PM_{2.5}$).

Human production of NO_2 and $PM_{2.5}$ is primarily from combustion, notably, from vehicles and industrial processes. Numerous studies have examined lung function in relation to long-term exposure to ambient levels of these air pollutants or to traffic emissions, but few have examined industrial emissions.[2] Of those studies, some have observed reductions in lung function among children living near industrial facilities,[5,6] but others have not.[7]

This article examines the relationship between long-term exposure to industrial air emissions of nitrogen oxides (NO_x) and $PM_{2.5}$ and lung function in a nationally representative sample of Canadian children and youth aged 6 to 18. The data are from the Canadian Health Measures Survey and the National Pollutant Release Inventory.

Methods

Canadian Health Measures Survey

The Canadian Health Measures Survey (CHMS) is an ongoing survey designed to provide direct health measures at the national level for people living in private households. Cycle 1 was conducted from March 2007 through February 2009, and collected information from respondents aged 6 to 79. Cycle 2 took place from August 2009 through November 2011, and collected data from respondents aged 3 to 79. Residents of First Nations Reserves or other Aboriginal settlements, institutions and some remote regions, and full-time members of the Canadian Forces were excluded. More than 96% of the population was represented. Ethics approval for the CHMS was obtained from Health Canada's Research Ethics Board.

The CHMS involves an in-home interview during which a questionnaire is administered. This is followed by a visit to a mobile examination centre (MEC) where physical measures (including spirometry to assess lung function) are taken, and additional questionnaires are administered. Participation is voluntary; respondents can opt out or refuse any part of the survey at any time. Written informed consent is obtained from respondents aged 14 or older. For younger children, a parent or legal guardian provides written consent, in addition to written assent from the child (where possible). After adjustments for the sampling strategy, the combined response rate for cycles 1 and 2 was 53.5%. Details about the survey, including the sampling strategy, are available at www.statcan.gc.ca/chms.

Spirometry was performed using a Fleisch pneumotachograph type spirometer (KoKo™, nSpire Longmont Co, USA) in accordance with the testing procedure in the revised joint American Thoracic Society/European Respiratory Society guidelines.[8] Technician training for the MEC was the same for all operators; ongoing quality control assessment was done manually and electronically. Only spirograms meeting international standards[8] were accepted at the time of testing. All tracings were reviewed by a qualified pulmonary function technician who made the final decision on acceptance or rejection of tracings from the field.[9] The lung function parameters examined in this study are the conventional spirometric indices used to

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detect impairment[10]: forced vital capacity (FVC), which measures the total volume exhaled after a maximum inspiration; 1-sec forced expiratory volume, which measures the maximum volume that can be exhaled within 1 sec (FEV_1); and the ratio of the two—FEV_1/FVC.

Respondents were not eligible for spirometry if they were younger than 6, older than 79, or 27 or more weeks' pregnant; had a heart attack or major surgery in the chest or abdomen in the previous three months or eye surgery in the past six weeks; reported taking medication for tuberculosis; had an acute respiratory tract infection (for example, cold, flu); or had other conditions that could make spirometry unsafe for the respondent[8] or yield results that were unreliable or unrepresentative of their usual lung function.

Respondents were classified as white or non-white based on their self-reported cultural or racial background. Education was classified into three categories (less than secondary school graduation, secondary school graduation or some postsecondary education, and postsecondary graduation) based on the highest level attained by a member of the respondent's household. Total household income was classified into three categories (low, middle, high), adjusted for household size. Respondents were considered to have a respiratory condition/symptom if they replied "yes" to one or more questions about diagnosed chronic conditions, wheezing, coughing, phlegm, and shortness of breath (Text table 1). Those who replied "no" to each question were classified as not having a respiratory condition/symptom.

Respondents were "regularly" exposed to second-hand smoke if they reported that they were exposed to second-hand smoke in their home every day or almost every day. To determine maternal smoking, mothers of respondents younger than age 12 were asked if they had smoked while pregnant with the respondent. Respondents had "a history of smoking" if they met one or more of the following conditions: reported smoking 100 or more cigarettes in their lifetime; reported currently being a daily or occasional smoker; or their cotinine concentration was more than 50ng/mL.[11] Free cotinine was measured from a spot midstream urine sample collected at the MEC and sent to the testing laboratory at the Institut national de santé publique du Québec (accredited under ISO 17025).

Age was calculated by subtracting the self-reported birth date from the clinic examination date. Standing height was measured to the nearest 0.1 cm using a ProScale M150 digital stadiometer (Accurate Technology Inc., Fletcher, USA). Weight was measured to the nearest 0.01 kg using a Mettler Toledo digital scale. Respondents were classified as obese or not obese according to World Health Organization criteria based on age, sex and body mass index (kg/m^2).[12]

Ambient temperature at the hour of data collection at the MEC was obtained from Environment Canada's National Climate and Data Information Archive (www.climate.weatheroffice.gc.ca). The concentration of NO_2 and $PM_{2.5}$ at the hour of data collection was obtained from the air monitoring station of the National Air Pollution Surveillance Network (www.ec.gc.ca/rnspa-naps) nearest to the MEC that recorded hourly measurements.

National Pollutant Release Inventory

The National Pollutant Release Inventory (NPRI) contains data on industrial emissions of air pollutants. The NPRI is Canada's legislated, publicly accessible inventory of pollutant releases into air, water and land, disposals, and transfers for recycling. It compiles information reported by facilities and published by Environment Canada under the authority of the *Canadian Environmental Protection Act, 1999*. In 2011, more than 8,000 facilities reported to the NPRI on more than 300 listed substances, including NO_x and $PM_{2.5.}$ NO_x includes nitric oxide (NO) and NO_2. Nitrous oxide (N_2O) was not included when calculating NO_x releases. Since NO_x is a mixture, both NO and NO_2 were expressed on an NO_2-equivalent basis before individual quantities were combined for reporting the total NO_x release.[13] Facilities are required to report releases of these substances if they exceed the specified reporting threshold of 20 tonnes for NO_x and 0.3 tonnes for $PM_{2.5}$. Details are available at: http://www.ec.gc.ca/inrp-npri/

Facility types were identified by North American Industry Codes in the NPRI. Of the 5,763 facilities required to report $PM_{2.5}$ emissions that were included in this study (within 25 km of CHMS respondents' residences), 62% were Manufacturing, 19% were Agriculture,

Text table 1
Lung function questions from Canadian Health Measures Survey used to define "respiratory condition or symptom"

Question	Age range
We are interested in "long-term conditions" which are expected to last or have already lasted 6 months or more and that have been diagnosed by a health professional.	
Do you have asthma? (yes/no)	6 to 18
Do you have chronic bronchitis? (yes/no)	6 to 18
Has your child had wheezing or whistling in the chest in the last 12 months? (yes/no)	6 to 12
In the last 12 months, has your child had a dry cough at night, apart from a cough associated with a cold or a chest infection? (yes/no)	6 to 12
Do you cough regularly? (yes/no)	13 to 18
Do you cough up phlegm regularly? (yes/no)	13 to 18
During the past year, have you had a cough where you brought up phlegm that lasted 3 months or more? (yes/no)	6 to 18
Do even simple chores make you short of breath? (yes/no)	6 to 18

Forestry, Fishing and Hunting, and 5% were Utilities. The largest numbers of facilities were Oil and Gas Extraction (n = 698), followed by Non-Metallic Mineral Mining and Quarrying (n = 375), Cement and Concrete Product Manufacturing (n = 346), Petroleum and Coal Product Manufacturing (n = 281), and Electric Power Generation, Transmission and Distribution (n = 169). Of the 3,776 facilities required to report NO_x emissions that were included in this study, 57% were Mining, Quarrying, and Oil and Gas Extraction, 35% were Manufacturing, and 2% were Transportation and Warehousing. The largest numbers of facilities were Oil and Gas Extraction (n = 1,802), Electric Power Generation, Transmission and Distribution (n = 188), Basic Chemical Manufacturing (n = 144), Pulp, Paper and Paperboard Mills (n = 140), and Water, Sewage and Other Systems (n = 84).

Annual total air emissions of NO_x and $PM_{2.5}$ for each facility for each year from 2007 to 2011, and their geographic coordinates were obtained from the NPRI database. For each pollutant, annual exposure from emissions was calculated for industrial sites within a radius of 25 km of respondents' residences. The geographic co-ordinates of their residences were determined from their six-digit postal code and PCCF+ software.[14] For each respondent, emissions from industrial sites within the specified radius were weighted [weight = $\exp(-0.5*(d/25)^2)$; d = distance from respondent's residence to industrial site][15] and then summed. Respondents were assigned the annual exposure for the calendar year in which they participated in the MEC component of the CHMS. Year-to-year emissions were highly correlated (Table 1).

Statistical analysis

Respondents were excluded from the analysis if they were not aged 6 to 18, or if their spirometry measures were of insufficient quality. Lung function reference equations differ by ethnic group, but sample sizes were too small to enable analysis of ethnicity other than white. Therefore, respondents were excluded if they were not white. This resulted in a final sample of 2,833: 1,429 (50.4%) males and 1,404 (49.6%) females.

Almost all (2,691 or 95%) of the 2,833 respondents had emissions of both NO_x and $PM_{2.5}$ within 25 km of their residence; 60 had only emissions of $PM_{2.5}$ within 25 km of their residence; and 82 did not have emissions of NO_x or $PM_{2.5}$ within that distance.

Descriptive statistics were calculated, overall and by sex. Univariate linear regressions were performed to identify significant associations between lung function parameters and industrial air emissions of $PM_{2.5}$ and NO_x. Lung function parameters were modelled as percent predicted based on the Global Lung Initiative prediction equations.[10] Separate analyses were performed for males and females.

For lung function parameters significantly associated with industrial air emissions ($p < 0.05$), multivariate linear regressions were performed to control for potential confounders. There were five nested models for each lung function parameter. Model 1 was the unadjusted model; Model 2 added respiratory condition/symptom; Model 3 added household income; Model 4 added short-term $PM_{2.5}$; and Model 5 added age.

Other potential confounders were: education, regular exposure to second-hand smoke in the home, maternal smoking while pregnant with the respondent, height, and obesity. However, because univariate linear regressions showed that they were not associated with the lung function parameters at the 0.10 level, they were not included in the adjusted models. Univariate linear regressions with lung function parameters showed that respiratory condition/symptom had the lowest p-value, followed by household income, short-term $PM_{2.5}$, and age; these variables were added to the nested models accordingly.

All estimates were based on weighted data. Survey weights for combining cycles 1 and 2 were used. Statistical analyses were performed with SAS and SUDAAN software. Standard errors, coefficients of variation, and 95% confidence intervals were calculated with the bootstrap technique.[16,17] The number of degrees of freedom was specified as 24 to account for the CHMS sample design.[18]

Table 1
Correlation matrix of year-to-year emissions for sum of industrial air emissions of nitrogen oxides and fine particulate matter within 25-km radius of residence of 2007 to 2011 Canadian Health Measures Survey respondents aged 6 to 18

Industrial air emission/Year	Year				
	2007	2008	2009	2010	2011
Nitrogen oxides					
2007	...	0.99	0.94	0.95	0.90
2008	0.99	...	0.96	0.97	0.91
2009	0.94	0.96	...	0.99	0.97
2010	0.95	0.97	0.99	...	0.97
2011	0.90	0.91	0.97	0.97	...
Fine particulate matter					
2007	...	0.92	0.88	0.87	0.79
2008	0.92	...	0.95	0.93	0.84
2009	0.88	0.95	...	0.96	0.81
2010	0.87	0.93	0.96	...	0.83
2011	0.79	0.84	0.81	0.83	...

... not applicable

$p < 0.0001$ for all correlations

Sources: National Pollutant Release Inventory; 2007 to 2009 and 2009 to 2011 Canadian Health Measures Survey, combined.

Results

Mean percent predicted lung function and industrial air emissions values, overall and by sex, are shown in Table 2.

Results of the unadjusted and adjusted regression models examining the association between industrial air emissions and lung function parameters are shown in Table 3. Emissions of NO_x were not significantly associated with lung func-

tion for males or females. By contrast, for males, emissions of $PM_{2.5}$ were significantly associated with FEV_1 and FEV_1/FVC, but not with FVC. For females, industrial air emissions of $PM_{2.5}$ were not associated with lung function.

The association between industrial air emissions of $PM_{2.5}$ and FEV_1 and FEV_1/FVC among males remained significant when adjusting for respiratory condition/symptom, household income, short-term $PM_{2.5}$ levels, and age. An increase of 190 tonnes of industrial air emissions within 25 km of residence was associated with a 1% reduction in percent predicted FEV_1; an increase of 370 tonnes was associated with a 1% reduction in percent predicted FEV_1/FVC.

Table 2
Mean percent predicted lung function and mean amount of industrial air emissions within 25 km of residence, by sex, household population aged 6 to 18, 2007 to 2011

	Total			Males			Females		
		95% confidence interval			95% confidence interval			95% confidence interval	
	Mean	from	to	Mean	from	to	Mean	from	to
Percent predicted lung function parameters†									
FVC	103.07	102.27	103.87	103.21	102.30	104.12	102.93	101.92	103.93
FEV_1	98.86	98.07	99.64	98.63	97.70	99.56	99.09	98.00	100.18
FEV_1/FVC	95.47	94.97	95.97	95.13	94.39	95.87	95.81	95.17	96.45
Industrial air emissions									
NO_x (tonnes)	2,372.34[E]	1,547.02	3,197.66	2,431.43[E]	1,589.65	3,273.22	2,312.64[E]	1,487.75	3,137.53
$PM_{2.5}$ (tonnes)	250.27	169.08	331.46	250.62	169.08	331.46	249.92	166.30	333.54

[E] interpret with caution
† based on Global Lung Initiative reference equations
FVC = forced vital capacity
FEV_1 = 1-sec forced expiratory volume
NO_x = nitrogen oxides
$PM_{2.5}$ = fine particulate matter
Source: 2007 to 2009 and 2009 to 2011 Canadian Health Measures Survey, combined.

Table 3
Regression coefficients relating percent predicted lung function parameters to industrial air emissions within 25 km of residence, by sex, household population aged 6 to 18, 2007 to 2011

	FVC				FEV_1				FEV_1/FVC			
		95% confidence interval				95% confidence interval				95% confidence interval		
Industrial airemission/ Sex	beta	from	to	p-value	beta	from	to	p-value	beta	from	to	p-value
$PM_{2.5}$												
Males												
Model 1	-0.003	-0.007	0.001	0.133	-0.006	-0.010	-0.002	0.005*	-0.003	-0.005	0.000	0.021*
Model 2	...	...	...	...	-0.005	-0.009	-0.002	0.004*	-0.003	-0.005	-0.001	0.017*
Model 3	...	...	...	...	-0.005	-0.009	-0.001	0.008*	-0.003	-0.005	0.000	0.025*
Model 4	...	...	...	...	-0.005	-0.009	-0.001	0.009*	-0.003	-0.005	0.000	0.028*
Model 5	...	...	...	...	-0.005	-0.009	-0.001	0.010*	-0.003	-0.005	0.000	0.025*
Females												
Model 1	-0.002	-0.005	0.001	0.157	-0.003	-0.006	0.000	0.060	-0.001	-0.004	0.002	0.546
NO_x												
Males												
Model 1	0.000	-0.001	0.000	0.307	0.000	-0.001	0.000	0.101	0.000	0.000	0.000	0.155
Females												
Model 1	0.000	-0.001	0.000	0.646	0.000	-0.001	0.000	0.080	0.000	0.000	0.000	0.099

... not applicable
* significant at $p < 0.05$
FVC = forced vital capacity
FEV_1 = 1-sec forced expiratory volume
$PM_{2.5}$ = fine particulate matter
NO_x = nitrogen oxides
Model 1 = unadjusted; Model 2 = Model 1 + respiratory condition/symptom; Model 3 = Model 2 + household income; Model 4 = Model 3 + short-term $PM_{2.5}$; Model 5 = Model 4 + age
Source: 2007 to 2009 and 2009 to 2011 Canadian Health Measures Survey, combined.

Discussion

The association between exposure to industrial air emissions of NO_x and $PM_{2.5}$ and lung function was examined in a nationally representative sample of Canadian children and youth aged 6 to 18, using data from the NPRI and the CHMS. The significant negative association between emissions of $PM_{2.5}$ and FEV_1 and FEV_1/FVC among males suggests that such emissions are related to airway obstruction in this group.

These findings are consistent with previous research. For example, a study in Argentina found that children aged 6 to 12 living near petrochemical plants had lower lung function (13% lower FEV_1 percent predicted) than those in two relatively unpolluted areas.[5] Levels of particulate matter, including $PM_{2.5}$, were higher near the petrochemical plants than in other parts of the city.[19] An analysis in Spain that compared the lung function of children aged 6 to 14 living in a municipality near a large oil refinery and liquid fuel gasification plant with that of children in a nearby rural municipality found that those in the petrochemical industry area had lower lung function (10.3% lower FEV_1).[6]

Not all research has reported significant associations. A study of 13- to 14-year-olds in Spain did not find differences in lung function between those living near petrochemical plants, those living in a city with medium vehicular traffic, or those in an area with low vehicular traffic and no industry.

What is already known on this subject?

- Long-term exposure to ambient air pollution, such as fine particulate matter and nitrogen dioxide, has been associated with adverse effects on children's lung function.
- Few studies have examined lung function in relation to industrial emissions of air pollutants.

What does this study add?

- The National Pollutant Release Inventory, Canada's legislated, publicly accessible inventory of pollutant releases, was used as a source of data for industrial air emissions.
- At ages 6 to 18, a significant association between industrial air emissions of fine particulate matter and lung function was apparent for males, but not females.

These inconsistent results may be due to differences in characteristics of the petrochemical sites in various studies, such as wind direction and speed, humidity, precipitation, crude oil quality, production technology, pollution control equipment, and other nearby industrial activities and sources of pollution. As well, the composition of $PM_{2.5}$ can vary substantially with its origin, and particles from various sources may have different toxicities.[20]

A strength of the current study is that industrial air emissions were assigned at the individual level, rather than at the community or municipal level based on proximity to a petrochemical plant.

Whether a gender difference exists in the relationship between air pollution and children's lung function is unclear. This study found a significant association for boys, but not girls, which is consistent with several other studies.[3,21-24] However, some research has reported stronger associations for girls,[25-27] or no differences.[4,28,29]

Gender differences in the health effects of exposure to particulate matter may be related to differences in particle deposition in the respiratory tract due to anatomical differences and ventilation dynamics, and this effect may depend on particle size.[30] In addition, even moderate physical activity can result in a total lung deposition rate three to five times greater than at rest owing to higher minute ventilation and a greater prevalence of oral breathing,[31,32] which bypasses the particle filtering that occurs when breathing through the nose. According to data for 2007 to 2009, boys were more physically active than girls,[33] which has been associated with time spent outdoors.[34,35] Variations in time outdoors, and resultant exposure to air pollutants, may have contributed to the gender differences reported in this study and others.

No significant association between industrial emissions of NO_x and lung function was observed. Although most studies have examined NO_2 in relation to respiratory health,[2] some have shown a significant association with NO_X and lung function.[4,36] However, those studies examined traffic-related NO_x, rather than industry-related NO_x. Studies employing residential proximity to highways and major roads as a measure of traffic-related air pollutants have used cut-points of 50m to 200m to identify those with greater exposure.[37,38] In the present analysis, facilities located much farther away (25 km) were considered relevant sources of industrial emissions of NO_x. Results based on a smaller radius might be different.

Limitations

This analysis has a number of limitations. Concentrations of industrial air emissions were not measured. NPRI data, which were used as a proxy for exposure to industrial emissions, reflect only emissions from facilities required to report to the NPRI. Facilities were required to report to the NPRI if one or more NPRI substances were manufactured, processed or otherwise used at the facility during the year, and the total number of hours worked at the facility exceeded the 20,000-hour employee threshold (about 10 full-time employees). However, there were exceptions (http://www.ec.gc.ca/inrp-npri/). Of facilities required to report, those with emissions below the reporting thresholds would not be included in the derivation of the industrial air emissions variables. Thus, emissions are underestimated to the extent that facilities emitting pollutants below the reporting threshold are located near respondents' residence.

Long-term exposure to industrial air emissions based on NPRI data is a variable that has not been validated. At-source monitors could theoretically be used to validate the amount of emissions reported by each facility, but could not validate respondent exposure. And while personal air monitors could measure respondent exposure, they would not be able to distinguish between industrial emissions and other sources of air pollution.

Directional effects of air pollution due to weather and climate, the effect of stack height, or the temporal patterns of releases were not taken into account. Further, information was not available about how long respondents had lived at the reported place of residence or the locations of respondents' schools.

The full effect of industrial emissions could not be examined because no CHMS respondents may have been living near some reporting facilities. The distribution of the total number of facilities that reported both NO_x and $PM_{2.5}$ emissions, NO_x emissions only, and $PM_{2.5}$ emissions only was approximately equal.[13] By contrast, the majority of respondents lived within 25 km of facilities that reported emissions of both NO_x and $PM_{2.5}$; none lived near facilities that reported just NO_x emissions. Only areas with a population of at least 10,000 and a maximum respondent travel distance of 50 km in urban areas and 100 km in rural areas were considered as potential CHMS collection sites.[9] The distribution of types of reporting facilities might have differed if

the survey had included respondents from areas with lower population densities. Alternatively, some reporting facilities may be located more than 25 km from residential areas. Determining the location of reporting facilities in relation to residential areas and population densities was beyond the scope of this study.

Conclusion

NPRI data have been used in the past to study environmental issues, such as pollution emissions by population socio-economic status and socio-cultural characteristics.[39,40] This is the first time they have been used to examine the relationship between industrial air pollution and measures of lung function.

A significant association emerged between industrial emissions of air pollutants and lung function. Specifically, a negative association was observed between $PM_{2.5}$ and FEV_1 and FEV_1/FVC for young males, but not young females. No association was apparent between emissions of NO_x and lung function. Further analyses of the gender differences reported in this study are warranted. ■

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