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Research article

The modifying effect of socioeconomic status on the relationship between traffic, air pollution and respiratory health in elementary schoolchildren

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ABSTRACT

The volume and type of traffic and exposure to air pollution have been found to be associated with respiratory health, but few studies have considered the interaction with socioeconomic status at the household level. We investigated the relationships of respiratory health related to traffic type, traffic volume, and air pollution, stratifying by socioeconomic status, based on household income and education, in 3591 schoolchildren in Windsor, Canada. Interquartile range changes in traffic exposure and pollutant levels were linked to respiratory symptoms and objective measures of lung function using generalised linear models for three levels of income and education. In 95% of the relationships among all cases, the odds ratios for reported respiratory symptoms (a decrease in measured lung function), based on an interquartile range change in traffic exposure or pollutant, were greater in the lower income/education groups than the higher, although the odds ratios were in most cases not significant. However, in up to 62% of the cases, the differences between high and low socioeconomic groups were statistically significant, thus indicating socioeconomic status (SES) as a significant effect modifier. Our findings indicate that children from lower socioeconomic households have a higher risk of specific respiratory health problems (chest congestion, wheezing) due to traffic volume and air pollution exposure.

1. Introduction

Urban air pollution exposure is associated with increased respiratory health effects (Brugha and Grigg, 2014). Traffic-related air pollution specifically has been linked to adverse respiratory health outcomes, and living near major roadways is associated with increased respiratory illness (Kim et al., 2004; Urman et al., 2014).

The city of Windsor, Ontario, is located on the USA-Canada border with the Ambassador Bridge linking the cities of Detroit and Windsor. It is the busiest international crossing between the two countries, and residents are affected by trans-boundary air quality issues due to the high density of traffic crossing from large trucks, cars, and commercial vehicles. A land use regression (LUR) study (Wheeler et al., 2008) to predict seasonal multiple-source pollutant concentrations of NO_2, SO_2 and volatile organic compounds indicated that concentrations increased in the city with proximity to the international border, with strong inter-pollutant correlations. These LUR models were applied in later studies to assess chronic air pollution exposure in schoolchildren (Cakmak et al., 2012; Dales et al., 2009, 2008).

Children are also more vulnerable to the negative health effects of ambient air pollution exposure (e.g., Confalonieri et al., 2007; Islam et al., 2007; Kovats and Hajat, 2008; O'Neill and Ebi, 2009). An increased breathing rate relative to body size, and an underdeveloped respiratory tract results in this heightened sensitivity, which also acts in combination with the harmful effects of high temperature (Karl et al., 2009). Many recent studies have examined the relationship between air quality and asthma in children (e.g., Barnett et al., 2005; Liu et al., 2009; To et al., 2013; Weinmayr et al., 2010), as asthma is a serious health and widespread chronic disease among children (Bryant-Stephens, 2009).

Abbreviations: NO_2, Nitrogen dioxide; part per billion (ppb), SO_2; sulphur dioxide, part per billion (ppb); $PM_{2.5}$, Particulate matter with a median aerodynamic diameter less than or equal to 2.5 μm.

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Air pollution exposure can also interact with socio-economic factors (Burra et al., 2009), for example, living in communities with lower household income and education levels has been shown to be associated with increased vulnerability to air pollution (Cakmak et al., 2007). Increased mortality in Hamilton, Ontario was associated with air pollution exposure, with low educational attainment and high manufacturing employment positively modifying the association, thus representing a proxy for poorer socio-economic conditions (Jerrett et al., 2004). However, questions surrounding modifying effects of education and income that are linked to air pollution exposure are largely unanswered in the field and a closer look at household level, rather than neighbourhood level, analysis is required to tease apart influential variables. Traffic density, socioeconomic status, and air pollution are associated with increases in mortality and respiratory illness, and living near major roadways is related to increases in respiratory illness and asthma in children (Dockery, 2002; McConnell et al., 2006). Concerns regarding the disparities in air pollution exposure among differing socioeconomic groups are an important focus of the environmental justice movement. For example, Foster and Fostert (1998) and Grineski et al. (2007) found that controlling for socioeconomics, indoor hazards, and industry allowed for the identification of ozone as the strongest predictor of asthma hospitalizations in Phoenix, Arizona. In Hamilton, Ontario, Buzzelli and Jerrett (2003) found that large differences appeared in relation to changing industrial structure, which were similar to results in the United States (Clark et al., 2014; Grineski et al., 2007; Pope, 2014). These findings and others indicate a continental, intra-urban environmental injustice as experienced by low income, vulnerable populations from exposure to higher levels of air pollution (Buzzelli and Jerrett, 2003).

In this study, we linked information concerning both local roadways and air pollution to respiratory health among elementary school children in Windsor, Canada. We used land use regression to derive estimates of pollutant exposures resolved to the level of each subject's postal code, and traffic density parameters, as these can better capture the complex nature of traffic pollution than can a single pollution measurement (Cakmak et al., 2012). From this, we used a cross-sectional analysis to test the hypothesis that indicators of socioeconomic status, such as income and education, modify the respiratory health effects of gaseous and particulate air pollution, as well as the effect of roadway or traffic density on children's respiratory health.

2. Methods

2.1. Study population

As in Cakmak et al. (2012), the study included children with and without asthma in grades 4–6 in the Windsor public school system. An estimated 7200 children were approached for inclusion in 2005, with 2328 participating. Family socio-economic status and medical history information were collected from the Windsor Children's Respiratory Health Study questionnaires (Dales et al., 2009). Participation was not mandatory and approval was obtained from the Research Ethics Committee of Health Canada. The parents of the children reported on whether their child had a respiratory infection in the past week, their place of residence, postal code, child asthma medication use, smoking in the home, and the presence of pets.

2.2. Exposure to traffic

The volume and type of traffic were collected for roadways in the vicinity of the subject's home in 2005 by a trained observer using an electronic counter within the city of Windsor's Public Works Department and Geomatics Division. See Cakmak et al. (2012) for a detailed description. The Turning Movement Count (TMC) is the volume of traffic on a roadway segment, separated into two time intervals: 0700–1000 h, 0700–1800 h, and by all vehicles or truck only. Totals were counted for both vehicles and large trucks. The counts were determined by the volume and direction of traffic entering or leaving the segment of roadway at adjacent intersections.

The distance of the child's home to various types of roadways was determined by creating a 200 m radius around each child's postal code address, centered on the given postal code, which has a resolution of approximately 30 detached homes on the same side of the street or one apartment building. This radius was chosen as traffic-related pollutants (i.e., nitrogen oxides, carbon monoxide, volatile organic compounds) peak close to roadways and fall to background levels approximately 200 m from the pollutant source (Gilbert et al., 2003). Exposure to traffic-related air pollution was calculated as the sum of the traffic counts on all roadways within this boundary.

2.3. Air pollution

Yearly city-wide levels of air pollution for 2005 were estimated by averaging measurements from two fixed monitors within the city for hourly fine particulate matter ($PM_{2.5}$, $\mu m\ m^{-3}$), nitrogen dioxide (NO_2, ppb), and sulphur dioxide (SO_2, ppb), obtained from Environment Canada's National Air Pollution Monitoring System (NAPS) and resolved to the participant's neighborhood using a land use regression model (see Dales et al., 2008 for a full description of the method). The model was developed using road network data, population and dwelling counts, industrial point sources, distance to the Ambassador Bridge, and population density.

2.4. Lung function

As detailed in Cakmak et al. (2012): shortly after the administration of the questionnaire in 2005, pulmonary function testing was performed once for each child at the school by certified respiratory health therapists using KoKo Spirometers™ (Ferraris CardioRespiratory, Pulmonary Data Services Inc., Louisville, CO), with the results adjusted for temperature, barometric pressure, age, height, and gender (Polgar and Promadhat, 1971). A maximum of eight FVC maneuvers were carried out in an attempt to achieve three acceptable flow-volume loops, with two being within 200 mL for FVC and FEV1. The value assigned to the participant was the largest acceptable value within 200 mL of a second value. Increased exhaled nitric oxide (eNO) was measured prior to spirometry with single-breath-on-line measures of eNO with an Eco Physics CLD AL MED chemiluminescence analyzer (Eco Medics AG, Duernten, Switzerland).

2.5. Respiratory symptoms

Respiratory symptoms were self-reported in response to the following questions: “Does he/she usually have a cough apart from colds?,” “Does this child's chest ever sound wheezy or whistling?,” “Has this child ever had an attack of wheezing that has caused him/her to be short of breath?,” “Within the past year has this child had a chest illness that kept him or her at home for three consecutive days or more?” and “Has a physician ever told you this child had asthma, and does he or she still have it?” Statistical analyses were completed for each symptom alone (Cold Cough, Asthma, Wheeze with Dyspnoea, Wheeze, Chest Congestion, Chest Illness), as well as for any occurrence of respiratory symptoms other than those mentioned.

2.6. Socioeconomics

Subjects were categorised into three parental/family income levels based on questionnaire responses: <$35,000, $35,000–80,000 and >$80,000; and into three parental/family education levels: less than high school, high school or community college, and university or higher.

2.7. Statistical analysis

Generalised Linear Mixed Models were used to test the association between traffic exposures and reported respiratory symptoms or lung function within each socioeconomic group. Assuming that the reported health status of the students was not independent within the same postal code, each postal code was taken as a random effect. Results were adjusted for race (Caucasian versus other), smokers at home, pets at home, acute respiratory illness (cold/bronchitis/pneumonia) in the preceding two weeks, any medication for wheezing/asthma in the preceding two weeks, percent of immigrants in census subdivision, and latitude and longitude of postal code representative point.

All main effects and first order interaction products were considered. If The Wald Chi-Square statistic *p*-value was less than 0.10 for a main effect or interaction product, it was retained. The final model contained the selected variables and covariates if they were significant at $p < 0.05$ or if they confounded the exposure-outcome relationship (i.e. a change of 10% in the coefficient for exposure). We then stratified the analysis by income and education. The final model variables were race (Caucasian versus other), smokers at home, pets at home, acute respiratory illness (cold/bronchitis/pneumonia) in the preceding two weeks, and any medication for wheezing/asthma in the preceding 2 weeks. These were selected on the whole sample and used in the subset analysis.

To test the sensitivity of the model, we examined reported respiratory symptoms “cough without cold”, “chest congestion” and any reported symptom for traffic count parameters by education level with and without subjects with current asthma. There were no significant differences between the results.

In order to test the differences between high and low SES, we fit a full model with main effects and an interaction between air pollution and indicator variables for each of the income and education variables, defining lowest income and lowest education as the reference groups, respectively. The p values for the interaction terms of air pollution and high SES groups are used to test whether the air pollution effect in the high education and high income groups were significantly different to the low education and low income groups, respectively. If the corresponding p value was less than 0.05, the air pollution effect was considered to be significantly different.

All data management and regression modeling were completed in SPLUS Version 6.2. For continuous exposure, the results were expressed as odds ratios (ORs) and 95 percent confidence intervals (CI) for an interquartile range increase in traffic (STC and TMC) or air pollutant exposure.

3. Results

3.1. Study population

Traffic exposure data was available for 2328 students, of which 1570 also had questionnaire data available. A total of 1528 had spirometry results and traffic count data, and of these, 1058 had exhaled nitric oxide results. Of these, the mean age of the children was eleven years of age, approximately half were male, and three-quarters were Caucasian. Just over half lived with pets at home, with 26.2% reporting at least one smoker in the home, and 0.2% of the children smoked. A total of 276 had a patient-reported history of asthma.

The largest groups reporting respiratory symptoms were families with high school education or less (1988 subjects), and families with $35,000–80,000 in income. A detailed breakdown of the number of subjects reporting respiratory illness by income and education level is presented in Table 1.

Truck turning movement counts ranged from 726 (±24) in families with a high school education or less to 930 (±32) for university educated families (Table 2). Turning movement counts from 0700 to 1800 were highest for families earning less than $35,000 and for University educated families. Pollutant exposures did not vary greatly across the different socioeconomic groups (Table 2). Turning movement counts between 0700 and 1800 h were better correlated with morning turning movement counts (0.75) than with truck turning movement counts (0.68).

A full model including the main effects and an interaction term between air pollution and indicator variables for each of income and education variables, with the lowest income and lowest education defined as the reference groups respectively, were fit. The observed small p values ($p < 0.05$) for interaction terms of air pollution and high SES groups in these models indicated that the effect of air pollution in high education and high income was significantly different from low education and low income, respectively. Those significant differences are indicated by asterisk (*) through Tables 3–6. The interaction terms between the factors other than SES and air pollution were not significant ($p > 0.05$).

3.2. Associations between traffic parameters and respiratory symptoms

The odds ratios (ORs) between reported traffic exposure parameters and respiratory symptoms were higher in the lower income level than in the highest income level (Table 3) for the majority of cases, and the difference between the two levels was significant for 43% of the results; however, the ORs were not statistically significant based on the income stratification. The highest odds ratios were observed for the lowest income level for chest congestion (OR = 1.18, 95% CI 0.96, 1.44) and cough without cold (OR = 1.14, 95% CI 0.99, 1.33) at an IQR range increase in truck turning movement counts. When compared to the highest income level, the lowest level showed 11% and 17% greater increases in odds of the given symptom (chest congestion and cough without

Table 1
Number of subjects reporting respiratory illness by income and education level.

		Cough without cold	Chest congestion	Current asthma	Wheeze with dyspnea	Wheeze	Chest illness	Any symptom	Total
Income	<$35,000	143	98	65	79	171	98	264	586
	$35–80,000	365	285	203	242	534	285	787	1782
	>$80,000	293	164	139	131	296	164	500	1223
Education	<High school (HS)	449	319	237	137	574	319	863	1988
	HS/college	194	131	85	187	232	131	389	959
	University+	118	97	85	128	195	97	299	644
	Total	801	547	407	452	1001	547	1551	3591

Table 2
Mean (and standard error) traffic counts and pollutant exposures by income and education level.

		All	<$35,000	$35–80,000	>$80,000	<High school (HS)	HS/college	University+
Traffic	Turning movement counts 0700–1000	1777 (±38)	1947 (±40)	1693 (±38)	1819 (±37)	1703 (±37)	1811 (±40)	1956 (±40)
	Truck turning movement counts 0700–1800	800 (±28)	852 (±26)	791 (±30)	790 (±24)	726 (±24)	867 (±30)	930 (±32)
	Turning movement counts 0700–1800	27,069 (±623)	31,378 (±677)	25,029 (±602)	27,978 (±622)	26,345 (±605)	26,159 (±621)	30,660 (±673)
Pollutant	NO_2	11.6 (0.03)	12.1 (0.04)	11.3 (0.02)	11.6 (0.03)	11.4 (0.02)	11.4 (0.03)	11.8 (0.03)
	SO_2	5.34 (0.01)	5.57 (0.01)	5.23 (0.01)	5.35 (0.01)	5.3 (0.01)	5.2 (0.01)	5.4 (0.01)
	$PM_{2.5}$	15.6 (0.02)	15.7 (0.02)	15.6 (0.01)	15.6 (0.01)	15.6 (0.01)	15.6 (0.02)	15.7 (0.02)

cold) occurring, although this was not statistically significant. The ORs for self-reported asthma and the presence of any symptom decreased with income for all traffic count parameters, but was not statistically significant.

By education level, traffic exposures were associated with higher ORs for the less educated families compared to those with higher education levels in almost all cases (Table 3), and the difference between the two education level was significant for 33% of the results. Statistically significant ORs for chest congestion were observed in subjects with High School (HS)/college education with an IQR increase in morning turning movement counts (OR = 1.21, 95% CI 1.01, 1.45), which was 31% higher than those with a University education. Statistically significant increases in ORs for chest congestion were also observed for an IQR increase in truck turning movement counts for subjects with less than high school education (OR = 1.17, 95% CI 1.01, 1.36) and HS/college education (OR = 1.32, 95% CI 1.06, 1.64), as well as full day turning movement counts in households with less than a high school education (OR = 1.12, 95% CI 1.0, 1.26). For self-reported wheezing, the lowest education level demonstrated statistically significant ORs for turning movement counts from 0700 to 1000 h (OR = 1.10, 95% CI 1.01, 1.20). An IQR increase in truck turning movement counts was significantly associated with an 18% increase in the OR for any respiratory symptom, but only for the children of parents with HS/college level education.

3.3. Associations between pollution exposure and respiratory symptoms

Odds ratios results between estimated levels of separate air pollution exposure to $PM_{2.5}$, NO_2, and SO_2 and respiratory symptoms are stratified into three income levels in Table 4. For all respiratory symptoms excluding cough without cold, the OR at the lowest income level was greater than at the highest income level for all three pollutants. For an IQR change in NO_2, significant associations were found with wheeze with dyspnea and chest illness. Wheeze with dyspnea was statistically significant at the lowest (OR = 1.53, 95% CI 1.11, 2.11), and intermediate (OR = 1.42, 95% CI 1.20, 1.96) income levels. The OR of chest illness was similar and statistically significant at both the lowest (OR = 1.51, 95% CI 1.06, 2.14) and intermediate (OR = 1.39, 95% CI: 1.05, 1.84) income levels. For all remaining results, the results were not statistically significant, although the difference between the highest and lowest income levels was significant in 52% of the cases.

When stratified by education level (Table 4), ORs for all respiratory conditions due to exposure to the three air pollutants were higher at the lowest compared to the highest education levels, and this difference was significant for 62% of the results. The OR was significant for chest congestion in households with parents obtaining less than high school education for all three pollutants: $PM_{2.5}$, OR = 1.12 (95% CI 1.00, 1.26); SO_2, OR = 1.12 (95% CI 1.00, 1.25), and NO_2, OR = 1.37 (95% CI 1.02, 1.83).

3.4. Associations between traffic exposure and lung function

The percent changes in lung function for an IQR change in traffic exposure, by income, were frequently below 0 (see Table 5). Overall, the change for the lowest income level was lower than that for the higher income level. Decrements in FEV_1 in the lowest income levels were significant for turning movement counts between 0700

Table 3
Odds ratios with 95% confidence intervals (CI) based on interquartile range (IQR) changes between traffic count parameters within 200 m of the neighborhood and respiratory symptoms or disorders within 1570 Windsor public school students 9–11 years old, by three income levels and three education levels. Only respiratory symptoms with at least one statistically significant result, where either the 95th percentile confidence intervals exclude 1 or the ORs are significantly different from the low socioeconomic level, are shown. Thus, most of the results for $35–80,000 income group, and HS/college education group with most of respiratory symptoms are not shown.

	SES	Cough without cold	Chest congestion	Current asthma	Wheeze	Chest illness	Any symptom
Turning movement counts 0700–1000 h (IQR = 2047.00)	**Income**						
	<$35,000	1.10 (0.97, 1.24)	1.07 (0.91, 1.26)	1.14 (0.92, 1.41)*	1.05 (0.89, 1.23)	1.11 (0.93, 1.33)	1.11 (0.96, 1.29)*
	>$80,000	1.07 (0.91, 1.26)	1.05 (0.84, 1.31)	1.01 (0.88, 1.16)*	1.07 (0.94, 1.2)	1.06 (0.91, 1.23)	1.01 (0.91, 1.12)*
	Education						
	<High school (HS)	1.07 (0.97, 1.17)	**1.13 (1.01, 1.26)***	1.04 (0.94, 1.15)	**1.10 (1.01, 1.20)**	1.08 (0.97, 1.2)	1.07 (0.99, 1.16)*
	University+	0.91 (0.78, 1.05)	0.88 (0.75, 1.05)*	1.01 (0.86, 1.18)	1.04 (0.90, 1.20)	1.05 (0.88, 1.26)	0.94 (0.82, 1.09)*
Truck turning movement counts between 0700 and 1800 h (IQR = 678.00)	**Income**						
	<$35,000	1.14 (0.99, 1.33)*	1.18 (0.96, 1.44)*	1.09 (0.85, 1.41)	1.08 (0.88, 1.31)	1.07 (0.89, 1.29)	1.13 (0.95, 1.36)*
	>$80,000	0.97 (0.79, 1.2)*	1.07 (0.82, 1.41)*	1.08 (0.90, 1.3)	1.10 (0.95, 1.27)	1.07 (0.92, 1.23)	1.04 (0.91, 1.17)*
	Education						
	<High school (HS)	1.08 (0.96, 1.21)*	**1.17 (1.01, 1.36)***	1.10 (0.91, 1.33)	1.11 (0.99, 1.23)	1.11 (0.97, 1.26)	1.08 (0.98, 1.19)*
	University+	0.9 (0.75, 1.08)*	0.91 (0.72, 1.15)*	0.97 (0.85, 1.11)	1.04 (0.88, 1.24)	1.04 (0.84, 1.29)	0.94 (0.8, 1.12)*
Turning movement counts between 0700 and 1800 h (IQR = 18,092.25)	**Income**						
	<$35,000	1.09 (0.98, 1.22)	1.14 (0.91, 1.43)*	1.09 (0.92, 1.31)	1.09 (0.93, 1.27)*	1.11 (0.93, 1.33)*	1.13 (0.98, 1.3)*
	>$80,000	1.01 (0.87, 1.19)	0.98 (0.85, 1.13)*	1.02 (0.89, 1.17)	0.96 (0.86, 1.07)*	1.00 (0.87, 1.14)*	1.00 (0.91, 1.1)*
	Education						
	<High school (HS)	1.08 (0.99, 1.18)*	**1.12 (1.00, 1.26)***	1.02 (0.91, 1.14)	1.07 (0.99, 1.16)*	1.08 (0.98, 1.2)	1.07 (0.99, 1.15)*
	University+	0.89 (0.77, 1.02)*	0.87 (0.73, 1.04)*	0.95 (0.84, 1.08)	0.9 (0.79, 1.03)*	1.02 (0.86, 1.2)	0.85 (0.75, 0.97)*

*Odds ratios significantly different between the high and low socioeconomic levels.
Bolded values indicate statistical significance.

Table 4
The odds ratios (95% confidence intervals) between pollutants and respiratory symptoms or disorders among 1570 Windsor public school students 9–11 years old, by three income levels and three education levels. . Only respiratory symptoms with at least one statistically significant result, where either the 95th percentile confidence intervals exclude 1 or the ORs are significantly different from the low socioeconomic level, are shown. Thus, most of the results for $35–80,000 income group, and HS/college education group with most of respiratory symptoms are not shown.

	SES	Cough without cold	Chest congestion	Current asthma	Wheeze with dyspnea	Wheeze	Chest illness	Any symptom
$PM_{2.5}$	**Income**							
(IQR = 1.33)	<$35,000	1.01 (0.87, 1.19)	1.14 (0.91, 1.43)*	1.08 (0.79, 1.48)	1.26 (0.89, 1.78)*	1.09 (0.93, 1.27)*	1.15 (0.80, 1.65)*	1.13 (0.98, 1.3)*
	>$80,000	1.09 (0.98, 1.22)	0.98 (0.85, 1.13)*	1.02 (0.89, 1.17)	0.97 (0.83, 1.12)*	0.96 (0.86, 1.07)*	1.00 (0.87, 1.14)*	1.0 (0.91, 1.1)*
	Education							
	<High school (HS)	1.08 (0.99, 1.18)*	**1.12 (1, 1.26)***	1.02 (0.91, 1.14)*	1.16 (0.89, 1.51)*	1.07 (0.99, 1.16)*	1.08 (0.98, 1.2)	1.07 (0.99, 1.15)*
	University+	0.89 (0.77, 1.02)*	0.87 (0.73, 1.04)*	0.67 (0.43, 1.05)*	0.99 (0.83, 1.19)*	0.9 (0.79, 1.03)*	1.02 (0.86, 1.2)	0.85 (0.75, 0.97)*
SO_2	**Income**							
(IQR = 0.92)	<$35,000	0.99 (0.85, 1.14)	1.12 (0.9, 1.39)*	1.04 (0.77, 1.42)	1.21 (0.81, 1.80)*	1.05 (0.9, 1.23)	1.18 (0.79, 1.76)*	1.07 (0.94, 1.23)
	>$80,000	1.07 (0.96, 1.19)	1.0 (0.86, 1.15)*	1.03 (0.9, 1.18)	1.02 (0.89, 1.17)*	1.00 (0.9, 1.10)	1.01 (0.50, 2.05)*	1.01 (0.92, 1.1)
	Education							
	<High school (HS)	1.05 (0.96, 1.13)*	**1.12 (1, 1.25)***	1.04 (0.94, 1.15)	1.06 (0.73, 1.53)	1.06 (0.98, 1.14)*	1.07 (0.98, 1.17)	1.04 (0.97, 1.11)*
	University+	0.88 (0.77, 1)*	0.88 (0.74, 1.04)*	0.84 (0.57, 1.24)	1.00 (0.85, 1.18)	0.88 (0.77, 1.00)*	1.0 (0.86, 1.17)	0.84 (0.74, 0.96)*
NO_2	**Income**							
(IQR = 2.27)	<$35,000	0.97 (0.84, 1.13)	1.07 (0.87, 1.33)	1.16 (0.79, 1.69)*	**1.53 (1.11, 2.11)***	1.05 (0.90, 1.23)	**1.51 (1.06, 2.14)***	1.07 (0.93, 1.23)
	$35–80,000	0.98 (0.90, 1.06)	1.06 (0.95, 1.18)	0.99 (0.71, 1.34)	**1.42 (1.30, 1.96)**	1.03 (0.95, 1.10)	**1.39 (1.05, 1.84)**	1.0 (0.93, 1.07)
	>$80,000	1.08 (0.97, 1.2)	0.99 (0.86, 1.14)	1.02 (0.89, 1.18)*	1.00 (0.87, 1.15)*	0.99 (0.90, 1.10)	1.03 (0.91, 1.17)*	1.01 (0.93, 1.1)
	Education							
	<High school (HS)	1.05 (0.96, 1.14)*	**1.37 (1.02, 1.83)***	1.03 (0.93, 1.15)	1.01 (0.92, 1.12)	1.06 (0.98, 1.14)	1.06 (0.97, 1.17)	1.04 (0.97, 1.11)*
	University+	0.88 (0.77, 1)*	0.85 (0.71, 1.01)*	0.94 (0.68, 1.30)	0.98 (0.84, 1.16)	0.87 (0.77, 1.00)	1.01 (0.86, 1.18)	0.84 (0.74, 0.96)*

*Odds ratios significantly different between the high and low socioeconomic levels.
Bolded values indicate statistical significance.

and 1000 h (−2.59%, 95% CI: −4.36, −0.82) and truck turning movement counts between 0700 and 1800 h (−3.75%, 95% CI: −5.57, −1.92). Similarly, for FVC, the decline was significant for the lowest income level for turning movement counts between 0700 and 1000 h (−2.97%, 95% CI: −4.06, −1.88), and truck turning movement counts between 0700 and 1800 h (−3.62%, 95% CI: −6.85, −0.39). For increased exhaled nitric oxide, the decline was significant for the medium income level for turning movement counts between 0700 and 1000 h (−4.6%, 95% CI: −7.58, −1.63). Differences between the high and low income levels were significant for FVC for all traffic counts, and for FEV for all but the truck turning movement counts.

Results demonstrating change in lung function by education level were more varied (Table 5) and did not demonstrate any ORs of statistical significance. The magnitude of the reductions in FEV_1 was least in the lowest education level than in the highest in all traffic exposures excluding turning movement counts between 0700 and 1800 h. Reductions in FVC were greater in the lower education level than the higher for all traffic exposures. For eNO, reductions were greater in the lower education level than the higher for all except turning movement counts between 0700 and 1000 h. The difference between the highest and lowest education levels was significant for FVC and turning movement counts between 0700 and 1800 h.

Table 5
The percentage change in respiratory function for an interquartile range change in traffic counts, by three income levels and three education levels [N = 1528 (1058 for eNO)]. . Only respiratory function with at least one statistically significant result, where either the 95th percentile confidence intervals exclude 1 or the ORs are significantly different from the low socioeconomic level, are shown. Thus, most of the results for $35–80,000 income group, and HS/college education group with most of respiratory function are not shown.

	SES	FEV_1[a]	FVC[b]	eNO[c]
Turning movement counts 0700–1000	**Income**			
(IQR = 2.39)	<$35,000	−2.43 (−5.86, 1)*	−2.72 (−5.44, 0.01)*	1.19 (−4.85, 7.22)
	>$80,000	−0.25 (−5.57, 5.06)*	−0.49 (−2.75, 1.78)*	1.63 (−6.94, 10.19)
	Education			
	<High school (HS)	−0.02 (−1.75, 1.71)	−0.73 (−2.61, 1.14)	1.67 (−2, 5.34)
	University+	0.66 (−2.27, 3.58)	0.14 (−1.54, 1.83)	2.3 (−3.98, 8.57)
Truck turning movement counts 0700–1800	**Income**			
(IQR = 2.57)	<$35,000	−3.19 (−7.64, 1.26)	−3.38 (−8.21, 1.45)*	0.45 (−4.31, 4.8)
	>$80,000	−0.24 (−2.12, 1.64)	−0.84 (−5.24, 3.56)*	1.35 (−6.75, 9.44)
	Education			
	<High school (HS)	−0.02 (−2.29, 2.24)	−1.02 (−3.48, 1.43)	2.56 (−2.25, 7.38)
	University+	0.56 (−2.12, 3.25)	−0.49 (−4.11, 3.13)	1.72 (−4.89, 8.33)
Turning movement counts 0700–1800	**Income**			
(IQR = 3.01)	<$35,000	**−3.75 (−5.57, −1.92)***	**−3.62 (−6.85, −0.39)***	0.67 (−5.1, 6.44)
	>$80,000	−1.15 (−6.26, 3.95)*	−0.98 (−5.41, 3.44)*	1.55 (−6.77, 9.88)
	Education			
	<High school (HS)	−0.23 (−2.65, 2.18)	−1.13 (−3.75, 1.49)*	0.35 (−4.69, 5.39)
	University+	−0.05 (−2.08, 1.99)	0.29 (−0.99, 1.57)*	1.89 (−4.35, 8.14)

*Odds ratios significantly different between the high and low socioeconomic levels.
Bolded values indicate statistical significance.
[a] Forced expiratory volume in one second (percent predicted).
[b] Forced vital capacity (percent predicted).
[c] Exhaled nitric oxide.

3.5. Associations between pollution exposure and lung function

For an IQR change in NO_2, FEV_1 declined significantly in the lowest income group (Table 6), −1.94% (95% CI: −3.57, −0.3). The decline in FEV_1 for an IQR change in SO_2 and NO_2 exposure was significantly different between the highest and lowest income groups. There was also a significant difference between the highest and lowest income groups for eNO for an IQR change in NO_2.

By education level, significant decreases in lung function were observed for an IQR change in SO_2 in subjects from families with a less than high school education, where FVC declined −1.27% (95% CI: −2.53, 0), and eNO declined −1.87% (95% CI: −3.41, −0.34). The difference between the high and low education levels were also significant for eNO (Table 6).

4. Discussion

Increased traffic density within 200 m of the subject's home and increases in ambient air pollution were both associated with increased respiratory symptoms. The odds ratios were higher in the lowest income and education levels for the majority of cases, and in select instances these increases were statistically significant. For example, associations by income level when testing traffic counts were not significant in any case; however, significant associations were present due to exposure to NO_2 for two respiratory outcomes. Significant results by education level were present when testing the odds of respiratory ailments due to both factors of traffic counts and direct air pollution exposure, where all three air pollutants resulted in significantly higher odds of chest congestion in households with parents having less than a high school education.

Although numerous studies have focused on the respiratory health outcomes in children due to air pollution or traffic exposures (e.g. Lin et al., 2005; Mazaheri et al., 2014; Vanos, 2014), very few studies have focused on the modifying effects of socioeconomic differences on respiratory ailments, specifically in children. Understanding the modifying effects of factors based on such differences aids in understanding many related explanatory findings and hypotheses discussed in the literature such as education (Cakmak et al., 2007), income, social isolation, and gender (Cakmak et al., 2006; Jerrett et al., 2004). The current study assessed how parental education and income may maybe effect modifiers on the results of child respiratory health associated with traffic and air pollution, demonstrating that on average a lower education and income result in a greater likelihood of respiratory ailments due to traffic or air pollution exposure. These socioeconomic indicators are closely related to many of the factors such as diet, smoking, and both indoor and outdoor air quality (McConnell et al., 2006; Prescott and Vestbo, 1999), and teasing apart which factors or pollutants lead to a higher risk poses a difficult challenge in this area of research (CA Pope and Dockery, 2006).

Associations between the distance from high-traffic roadways to residential areas and the prevalence of respiratory illness and symptoms have been found by a number of researchers. McConnell et al. (2006) found that residing within 75 m of a major road was associated with increased risk of asthma (OR = 1.29, 95% CI 1.01, 1.86). This higher risk decreased to background rates at 150 m–200 m from the road. Dales et al. (2009) investigated roadway length around neighbourhoods in Windsor, Ontario and the association with children's respiratory health. Each kilometre of any type of roadway within 200 m of the subject's neighbourhood was significantly associated with wheezing, wheezing and asthma, and an increase in exhaled nitric oxide (eNO), a measure of airway inflammation in asthma. However, they did not find significant reduction in ventilatory lung function assessed by one-second forced expired volume (FEV_1) or forced vital capacity (FVC). In a study on the same population sample, Dales et al. (2008) derived an exposure metric based on ambient air pollution and length of roadways within a 200 m radius using land-use regression modeling. Results indicated negative but non-significant associations between individual air pollutants and lung function.

Cakmak et al. (2012) studied the same Windsor population and found that increased traffic counts within a 200 m radius caused increased respiratory symptoms and statistically significant declines in pulmonary function in children. Traffic counts were associated with statistically significant reductions in FVC in children, and were more strongly associated with a history of asthma.

Table 6
The percentage change in respiratory function among 1528 (1058 for eNO) Windsor public school students 9–11 years old, for an interquartile range change in pollutant, by three income levels and three education levels. . Only respiratory function with at least one statistically significant result, where either the 95th percentile confidence intervals exclude 1 or the ORs are significantly different from the low socioeconomic level, are shown. Thus, most of the results for $35–80,000 income group, and HS/college education group with most of respiratory function are not shown.

	SES	FEV_1[a]	FVC[b]	eNO[c]
$PM_{2.5}$	**Income**			
	<$35,000	−1.34 (−3.27, 0.58)	−0.09 (−0.97, 0.8)	−0.1 (−1.01, 0.81)
	>$80,000	−0.77 (−1.65, 0.12)	0.83 (−0.13, 1.78)	0.8 (−0.98, 2.58)
	Education			
	<High school (HS)	−0.55 (−2.01, 0.92)	−0.68 (−1.79, 0.42)	0.11 (−3.06, 3.28)
	University+	0.7 (−0.08, 1.48)	−0.82 (−1.68, 0.04)	0.73 (−0.91, 2.37)
SO_2	**Income**			
	<$35,000	−2.34 (−5.12, 0.43)*	−0.58 (−1.82, 0.67)	−1.55 (−3.21, 0.12)
	>$80,000	−0.68 (−1.52, 0.16)*	−0.62 (−1.57, 0.33)	−0.49 (−1.77, 0.79)
	Education			
	<High school (HS)	−0.6 (−3.29, 2.1)	**−1.27 (−2.53, 0)**	**−1.87 (−3.41, −0.34)***
	University+	−0.52 (−1.29, 0.26)	−0.44 (−1.33, 0.44)	0.14 (−1.61, 1.89)*
NO_2	**Income**			
	<$35,000	**−1.94 (−3.57, −0.3)***	−1.13 (−2.29, 0.02)	−2 (−5.68, 1.67)*
	$35–80,000	0.94 (−0.34, 2.21)	0.73 (−0.24, 1.69)	0.72 (−1.19, 2.63)
	>$80,000	−0.19 (−0.77, 0.39)*	−0.25 (−0.9, 0.4)	0.76 (−0.39, .9)*
	Education			
	<High school (HS)	−0.37 (−1.4, 0.67)	−0.13 (−0.92, 0.66)	0.41 (−1.71, 2.53)
	University+	−0.07 (−0.61, 0.47)	−0.03 (−0.64, 0.57)	−0.15 (−1.35, 1.05)

*Odds ratios significantly different between the high and low socioeconomic levels.
Bolded values indicate statistical significance.
[a] Forced expiratory volume in one second (percent predicted).
[b] Forced vital capacity (percent predicted).
[c] Exhaled nitric oxide.

Many studies (Dales et al., 2009, 2008; Holguin et al., 2007) have used traffic density to assess risk of developing respiratory symptoms in children, but did not find relationships with ventilatory lung function measurements such as FVC or FEV_1. Comparing the latter two studies (i.e., Dales et al. (2008) and Cakmak et al. (2012)) reveals that traffic counts may be a better representation of exposure effects to the magnitude of traffic than road density (or traffic density), yet effect modification by socioeconomics were not addressed. The present study provides further evidence that traffic counts can effectively represent traffic exposure and that this association is significant in those with lower education.

Our findings of a relationship between self-reported respiratory ailments and $PM_{2.5}$ is corroborated by Liu et al. (2009) who found that an average three-day $PM_{2.5}$ exposure in children of 5.4 $\mu g\ m^{-3}$ resulted in a significantly decreased forced expiratory flow (FEF) of −3.0% (95% CI − 4.7−1.2). Traffic counts and density can also be an indicator for noise, stress, and lower socio-economic status. Socio-economic status is an important risk factor contributing to children's respiratory illness (Almqvist et al., 2005; Cakmak et al., 2007; Claudio et al., 2006). Increased susceptibility to air pollution, and its association with lower socioeconomic position, may be due to less dietary fruits and vegetables, and poorer access or utilisation of medical care (Cakmak et al., 2006; O'Neill et al., 2003; Sexton et al., 1993). An elevated response to air pollution in people with lower socioeconomic status may be mediated via stress-related pathways (Clougherty and Kubzansky, 2009).

Further studies addressing socioeconomic factors as effect modifiers in children have found that lower socioeconomic positions result in increased negative health outcomes. Results from Nishimura et al. (2013) added to evidence showing that traffic-related pollutants may be causally related to childhood asthma, where effects of NO2 exposure were highest in Latino and African American children. Moreover, Burra et al. (2009) found that the risk ratios of ambulatory physician visits for a low socioeconomic group in Toronto, Canada were significantly greater than those for those in a high socioeconomic position when examining SO2 and PM2.5. In exploring the role of race, ethnicity, and insurance status in modifying the effects of air pollution on children's asthma hospitalizations in Phoenix, Arizona (US), Grineski et al. (2010) used insurance status as a proxy for income. They found significantly increased risks of hospital visits for children without insurance (and thus of low income). Similar results of higher hospitalization due to air pollution exposure were found for low SES children by Lee et al. (2006).

Additionally, people with lower socioeconomic status may be at higher risk from air pollution as a result of greater exposure. Low income and minority communities also tend to live near heavy traffic areas in many large cities, and are hence disproportionately exposed to poor air quality (Bell et al., 2005; Carrier et al., 2014; Crouse et al., 2009; Grineski et al., 2007; Pope, 2014). Issues of equity are an important focus when analyzing socioeconomic status factors as effect modifiers. Inequity also poses challenges for public health: residents of high exposure communities who suffer adverse health outcomes related to air pollution (e.g., asthma) are more likely to suffer from long-term deterioration in quality of life.

4.1. Study strengths and limitations

A full model with main effects and an interaction between air pollution and indicator variables for each of the stratified income and education levels-defining lowest income and lowest education as the reference groups, respectively-provided *p*-values that enabled us to test the significance of differences between high and low SES directly. We found significant interaction terms between parental income and education levels and air pollutants and traffic volume as a result of these tests. However, the interaction terms between the factors other than SES and air pollution and traffic were not significant ($p > 0.05$).

The information gained from spirometry is clinically important, used to determine the degree of impairment from respiratory disease, and to diagnose chronic obstructive lung disease and acute asthma exacerbations. Although the magnitude of changes in spirometry-derived variables were relatively small, levels of ambient air pollution, which are associated with changes of this magnitude, are also associated with a similar percentage increase in hospitalizations for respiratory disease among certain socio-demographic subgroups (Cakmak et al., 2011). Confounding of the observed association between air pollutants and lung function is a possibility, but it would require a factor that is associated with the exposure and is also a risk factor for the outcome. Respiratory health effects were related to the annual averaged air pollution exposure and were hence more likely to represent chronic effects. Socioeconomic status itself combines many different elements that may contribute to differential health responses to air pollution: nutrition, housing quality, employment, and pollutant exposures at home, work, or at school, which are not necessarily captured by family income or education data. We note limitations of the study related to the study design that may give less confidence in results, such as the sample size of lung function analysis, the self-reporting of symptoms, and other potential confounders that we did not include in the model (e.g., time spent indoors or outdoors, diet) but may be important. Furthermore, to examine the modifying effects of education and income we stratify the data into subgroups, each with about 16−49% of the reported symptoms. Stratified analysis reduces the sample size and increases standard errors of estimates within each sub-analysis, thus, reduces the likelihood of finding significant effect modification. Almost all of the statistically significant associations between exposure and respiratory health are observed in low SES, while no significant associations were found in high SES groups despite having higher prevalence of the respiratory symptoms, thus, having higher power to detect the exposure effect in high income group. This also confirms that observed effect modifications are unlikely due to chance alone. Additionally, although the ORs observed were in most cases not statistically significant, the high rate of occurrence of this income group difference also indicates it was not by chance alone, and the risk estimates may have been attenuated by the small sample size for each group. Overall, the results corroborate general relationships between air pollution, traffic exposure and health, but more importantly, we also show that these relationships are modified by SES.

4.2. Conclusion

To more fully investigate traffic-related air pollution and its impact on population health, it is important to understand the modifying effects of socioeconomic status. Here we investigated the relationships of respiratory health related to traffic and air pollution, stratifying by socioeconomic status to study effect modification. Our study suggests that children from lower income and less well-educated households are at an increased risk of some respiratory illness and reductions in lung function, both from increased exposure to traffic and from ambient air pollution. In the majority of instances, odds ratios were larger for the children of low income or less educated families, and decreases in lung function parameters were greater in these groups. Even though the ORs observed were in most cases not statistically significant, the high occurrence of this difference indicates it was not by chance alone, and the risk estimates may have been attenuated by the small sample size for each group. Our results are suggestive of effect modification by socioeconomic status, and highlight social issues of environmental differences found in many large metropolitan areas.

Competing financial interests declaration

All authors have no competing financial interests.

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References

Almqvist, C., Pershagen, G., Wickman, M., 2005. Low socioeconomic status as a risk factor for asthma, rhinitis and sensitization at 4 years in a birth cohort. Clin. Exp. Allergy 35, 612–618.
Barnett, A.G., Williams, G.M., Schwartz, J., Neller, A.H., Best, T.L., Petroeschevsky, A.L., Simpson, R.W., 2005. Air pollution and child respiratory health: a case-crossover study in Australia and New Zealand. Am. J. Respir. Crit. Care Med. 171, 1272–1278.
Bell, M.L., O'Neill, M.S., Cifuentes, L. a., Braga, A.L.F., Green, C., Nweke, A., Rogat, J., Sibold, K., 2005. Challenges and recommendations for the study of socioeconomic factors and air pollution health effects. Environ. Sci. Policy 8, 525–533.
Brugha, R., Grigg, J., 2014. Urban air pollution and respiratory infections. Paediatr. Respir. Rev. 15, 194–199.
Bryant-Stephens, T., 2009. Asthma disparities in urban environments. J. Allergy Clin. Immunol. 123, 1199–1206.
Burra, T., Moineddin, R., Agha, M.M., Glazier, R.H., 2009. Social disadvantage, air pollution, and asthma physician visits in Toronto, Canada. Environ. Res. 109, 567–574.
Buzzelli, M., Jerrett, M., 2003. Spatiotemporal perspectives on air pollution and environmental justice in Hamilton, Canada, 1985–1996. Ann. Assoc. Am. Geogr. 93, 557–573.
Cakmak, S., Dales, R.E., Judek, S., 2006. Do gender, education, and income modify the effect of air pollution gases on cardiac disease? J. Occup. Environ. Med. 48, 89–94.
Cakmak, S., Dales, R.E., Judek, S., 2007. Respiratory health effects of air pollution gases: modification by education and income. Arch. Environ. Occup. Health 61, 5–10.
Cakmak, S., Dales, R.E., Rubio, M.A., Vidal, C.B., 2011. The risk of dying on days of higher air pollution among the socially disadvantaged elderly. Environ. Res. 111, 388–393.
Cakmak, S., Mahmud, M., Grgicak-Mannion, A., Dales, R.E., 2012. The influence of neighborhood traffic density on the respiratory health of elementary schoolchildren. Environ. Int. 39, 128–132.
Carrier, M., Apparicio, P., Séguin, A.-M., Crouse, D., 2014. The application of three methods to measure the statistical association between different social groups and the concentration of air pollutants in Montreal: a case of environmental equity. Transp. Res. Part D. Transp. Environ. 30, 38–52.
Clark, L.P., Millet, D.B., Marshall, J.D., 2014. National patterns in environmental injustice and inequality: outdoor NO2 air pollution in the United States. PLoS One 9, e94431.
Claudio, L., Stingone, J.A., Godbold, J., 2006. Prevalence of childhood asthma in urban communities: the impact of ethnicity and income. Ann. Epidemiol. 16, 332–340.
Clougherty, J.E., Kubzansky, L.D., 2009. A framework for examining social stress and susceptibility to air pollution in respiratory health. Environ. Health Perspect. 117 (9), 1381–1388.
Confalonieri, U., Menne, B., Akhtar, R., Ebi, K., Hauenque, M., Kovats, R., Revich, B., Woodward, A., 2007. Human Health. Climate Change 2007: Impacts, Adaptation and Vulnerability (Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, UK).
Crouse, D.L., Ross, N.A., Goldberg, M.S., 2009. Double burden of deprivation and high concentrations of ambient air pollution at the neighbourhood scale in Montreal, Canada. Soc. Sci. Med. 69, 971–981.
Dales, R., Wheeler, A., Mahmud, M., Frescura, A.M., Smith-Doiron, M., Nethery, E., Liu, L., 2008. The influence of living near roadways on spirometry and exhaled nitric oxide in elementary schoolchildren. Environ. Health Perspect. 116, 1423–1427.
Dales, R., Wheeler, A.J., Mahmud, M., Frescura, A.-M., Liu, L., 2009. The influence of neighborhood roadways on respiratory symptoms among elementary schoolchildren. J. Occup. Environ. Med. 51, 654–660.
Dockery, D.W., Pope III, C.A., 2002. Outdoor particulates. In: Steenland, K., Savitz, D.A. (Eds.), Topics in Environmental Epidemiology. Oxford University Press, New York, pp. 119–166.
Foster, S., Fostert, S., 1998. Justice from the ground up: distributive inequities, grassroots resistance, and the transformative politics of the environmental justice movement. Calif. Law Rev. 86.
Gilbert, N.L., Woodhouse, S., Stieb, D.M., Brook, J.R., 2003. Ambient nitrogen dioxide and distance from a major highway. Sci. Total Environ. 312, 43–46.
Grineski, S., Bolin, B., Boone, C., 2007. Criteria air pollution and marginalized populations: environmental inequity in metropolitan Phoenix, Arizona. Soc. Sci. Q. 88, 535–554.
Grineski, S.E., Staniswallis, J.G., Peng, Y., 2010. Children's asthma hospitalizations and relative risk due to nitrogen dioxide (NO_2): effect modification by race, ethnicity and insurance status. Environ. Res. 110, 178–188.
Holguin, F., Flores, S., Ross, Z., Cortez, M., Molina, M., Molina, L., Rincon, C., Jerrett, M., Berhane, K., Granados, A., Romieu, I., 2007. Traffic-related exposures, airway function, inflammation, and respiratory symptoms in children. Am. J. Respir. Crit. Care Med. 176, 1236–1242.
Islam, T., Gauderman, W.J., Berhane, K., McConnell, R., Avol, E., Peters, J.M., Gilliland, F.D., 2007. Relationship between air pollution, lung function and asthma in adolescents. Thorax 62, 957–963.
Jerrett, M., Burnett, R.T., Brook, J., Kanaroglou, P., Giovis, C., Finkelstein, N., Hutchison, B., 2004. Do socioeconomic characteristics modify the short term association between air pollution and mortality? Evidence from a zonal time series in Hamilton, Canada. J. Epidemiol. Community Heal 58, 31–40.
Karl, T.R., Melillo, J.M., Peterson, T.C., 2009. Global Climate Change Impacts in the United States. Cambridge University Press.
Kim, J.J., Smorodinsky, S., Lipsett, M., Singer, B.C., Hodgson, A.T., Ostro, B., 2004. Traffic-related air pollution near busy roads: the east bay Children's respiratory health study. Am. J. Respir. Crit. Care Med. 170, 520–526.
Kovats, R.S., Hajat, S., 2008. Heat stress and public health: a critical review. Annu. Rev. Public Health 29, 41–55.
Lee, J.T., Son, J.Y., Kim, H., Kim, S.Y., 2006. Effect of air pollution on asthma-related hospital admissions for children by socioeconomic status associated with area of residence. Archives Environ. Occup. Health 61 (3), 123–130.
Lin, M., Stieb, D.M., Chen, Y., 2005. Coarse particulate matter and hospitalization for respiratory infections in children younger than 15 years in Toronto: a case-crossover analysis. Pediatrics 116, e235–e240.
Liu, L., Poon, R., Chen, L., Frescura, A.-M., Montuschi, P., Ciabattoni, G., Wheeler, A., Dales, R., 2009. Acute effects of air pollution on pulmonary function, airway inflammation, and oxidative stress in asthmatic children. Environ. Health Perspect. 117, 668.
Mazaheri, M., Clifford, S., Jayaratne, R., Mokhtar, M.A.M., Fuoco, F., Buonanno, G., Morawska, L., 2014. School children's personal exposure to ultrafine particles in the urban environment. Environ. Sci. Technol. 48, 113–120.
McConnell, R., Berhane, K., Yao, L., Jerrett, M., Lurmann, F., Gilliland, F., Künzli, N., Gauderman, J., Avol, E., Thomas, D., Peters, J., 2006. Traffic, susceptibility, and childhood asthma. Environ. Health Perspect. 114, 766–772.
Nishimura, K.K., Galanter, J.M., Roth, L.A., Oh, S.S., Thakur, N., Nguyen, E.A., Brigino-Buenaventura, E., 2013. Early-life air pollution and asthma risk in minority children. The GALA II and SAGE II studies. Am. J. Respir. Crit. care Med. 188 (3), 309–318.
O'Neill, M.S., Ebi, K.L., 2009. Temperature extremes and health: impacts of Climate variability and change in the United States. J. Occup. Environ. Med. 51, 13–25.
O'Neill, M.S., Jerrett, M., Kawachi, I., Levy, J.I., Cohen, A.J., Gouveia, N., Wilkinson, P., Fletcher, T., Cifuentes, L., Schwartz, J., Pollution, W. on A., Conditions, S, 2003. Health, Wealth, and air pollution: advancing theory and methods. Environ. Health Perspect. 111, 1861–1870.
Polgar, G., Promadhat, V., 1971. Pulmonary Function Testing in Children. techniques and standards, Philadelphia.
Pope, R.L., 2014. Spatiotemporal Patterns, Monitoring Network Design, and Environmental Justice of Air Pollution in the Phoenix Metropolitan Region: a Landscape Approach.
Pope III, C.A., Dockery, D., 2006. Health effects of fine particulate air pollution: lines that connect. J. Air Waste Manage. Assoc. 56, 709–742.
Prescott, E., Vestbo, J., 1999. Socioeconomic status and chronic obstructive pulmonary disease. Thorax 54, 737–741.
Sexton, K., Gong, H., Bailar, J., Ford, J., GOld, D., Lambert, W., Utell, M., 1993. Air pollution health risks: do class and race matter? Toxicol. Ind. Health 9.
To, T., Shen, S., Atenafu, E.G., Guan, J., McLimont, S., Stocks, B., Licskai, C., 2013. The air quality health index and asthma morbidity: a population-based study. Environ. Health Perspect. 121, 46.
Urman, R., McConnell, R., Islam, T., Avol, E.L., Lurmann, F.W., Vora, H., Linn, W.S., Rappaport, E.B., Gilliland, F.D., Gauderman, W.J., 2014. Associations of children's lung function with ambient air pollution: joint effects of regional and near-roadway pollutants. Thorax 69, 540–547.
Vanos, J.K., 2014. Children's health and vulnerability in outdoor microclimates: a comprehensive review. Environ. Int. 76, 1–15.
Weinmayr, G., Romeo, E., De Sario, M., Weiland, S.K., Forastiere, F., 2010. Short-term effects of PM10 and NO2 on respiratory health among children with asthma or asthma-like symptoms: a systematic review and meta-analysis. Environ. Health Perspect. 118, 449.
Wheeler, A.J., Smith-Doiron, M., Xu, X., Gilbert, N.L., Brook, J.R., 2008. Intra-urban variability of air pollution in Windsor, Ontario–Measurement and modeling for human exposure assessment. Environ. Res. 106, 7–16.