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RESEARCH ARTICLE

Effects of air pollution on lung function and symptoms of asthma, rhinitis and eczema in primary school children

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Abstract Health effects of ambient air pollution were studied in three groups of schoolchildren living in areas (suburban, urban and urban-traffic) with different air pollution levels in Eskişehir, Turkey. This study involved 1,880 students aged between 9 and 13 years from 16 public primary schools. This two-season study was conducted from January 2008 through March 2009. Symptoms of asthma, rhinitis and eczema were determined by the International Study of Asthma and Allergies in Childhood questionnaire in 2008. Two lung function tests were performed by each child for summer and winter seasons with simultaneous ambient air measurements of ozone (O_3), nitrogen dioxide (NO_2) and sulfur dioxide (SO_2) by passive sampling. Effects of air pollution on impaired lung function and symptoms in schoolchildren were estimated by multivariate logistic regression analyses. Girls with impaired lung function (only for the summer season evaluation) were more observed in suburban and urban areas when compared to urban-traffic area ([odds ratio (OR)=1.49; 95 % confidence interval (CI) 1.04–2.14] and [OR=1.69 (95 % CI 1.06–2.71)] for suburban vs. urban-traffic and urban vs. urban-traffic, respectively). Significant association between ambient ozone concentrations and impaired lung function (for an increase of 10 $\mu g\ m^{-3}$) was found only for girls for the summer season evaluation [OR=1.11 (95 % CI 1.03–1.19)]. No association was found for boys and for the winter season evaluation. No association was found between any of the measured air pollutants and symptoms of current wheeze, current rhinoconjunctivitis and current itchy rash. The results of this study showed that increasing ozone concentrations may cause a sub-acute impairment in lung function of school aged children.

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Introduction

Previous epidemiological studies have reported that children and elderly people are more susceptible to both the acute and chronic adverse effects of ambient air pollution (Shannon et al. 2004; WHO 2005; Salvi 2007; Bateson and Schwartz 2008; Tabaku et al. 2011). Adverse effects of air pollution on children's health have been indicated in previous studies (Brunekreef et al. 1995; Brunekreef and Holgate 2002; WHO 2003, 2005; Schwartz 2004; Curtis et al. 2006). Reduced lung function, exacerbation of asthma, increased respiratory diseases and increased allergic diseases are considered to be among the typical health effects of air pollution on children's health. The associations between air pollution exposure and respiratory health of children living in Europe, USA, Canada, Australia and some of the other developed countries has been reported (Dockery et al. 1996; Raizenne et al. 1996; Boezen et al. 1999; Gauderman et al. 2000; Jalaludin et al. 2000). There are relatively few number of studies about air pollution and children's health in Turkey (Tecer et al. 2008; Gül et al. 2011).

Eskişehir is an urban area in central Anatolia with a moderate level of ambient air pollution. Domestic heating and traffic, rather than the industry, are responsible for the pollution in the city (Özden et al. 2008; Gaga and Arı 2011). The study presented here is a part of MATRA project (supported by Dutch government) carried out in Eskişehir to assess the adverse effect of air pollution on children's health between the years of 2008 and 2010. This study presents the results of the health survey. Detailed evaluation of ambient air quality before and during the health survey is given in a separate study (Gaga et al. 2012).

The objectives of this study were to assess the effect of ambient air pollution on (1) lung function and (2) current symptoms of asthma, rhinitis and eczema in schoolchildren by applying spirometry and the International Study of Asthma and Allergies in Childhood (ISAAC) questionnaire, respectively.

Materials and methods

Study area and population

Eskişehir is an intermediate size urban area in Turkey located at the northwest part of the central Anatolia, with a population of approximately 600,000 inhabitants. Fossil fuel consumption for domestic heating and traffic is the main polluting source of air pollution in the Eskişehir city. Domestic heating (for SO_2 and PM) and traffic (for NO_x and VOCs), rather than the industry, are responsible for the pollution in the city. Coal usage in domestic heating has been gradually replaced with natural gas since 1996. However, approximately 50 % of the residences use coal for heating in winter time. Although Eskişehir is not a heavily industrialized city, there exist some industrial plants. The main industrial activities in the vicinity of the residential area are a sugar factory, a locomotive engine factory and a plane engine factory (locations shown in Fig. 1). Small- and medium-sized plants exist in the industrial zone at the southeast part of the city. Ceramics and food industry are dominant industrial activities in the industrial zone. Natural gas is used for energy production almost in all industrial plants in this zone (Çınar 2003; Özden et al. 2008; Gaga et al. 2012).

Study area was classified into three regions which have different levels of air pollution: suburban (R1), urban (R2) and urban-traffic (R3). These three different regions were selected based on results of an extensive passive sampling campaign, population density data and former emission inventory studies in the residential area of Eskişehir (Özden et al. 2008; Gaga et al. 2012). Traffic volume data of major streets in the proximity of selected primary schools were gathered from former data belonging to Municipality of Eskişehir. Traffic measurements were carried out manually at 33 major arterial roads in the city. Figure 1 shows the location of the selected primary schools in each region.

Region 1 (R1) represents the suburban area in the outer zone of Eskişehir which is far away from the city center. Population density (2,750 capita km^{-2}) and traffic density (traffic volume of <5,000 vehicles day^{-1} measured at major roads closest to selected schools in the area) is quite low in this area. Natural gas is the main source of heating in this region and coal consumption is very low. Educational level of residents is higher in this region. Region 2 (R2) represents the urban area that has higher population density (5,000 capita km^{-2}) and similar traffic volume (<5,000 vehicles day^{-1}) when compared to region 1. Coal is the main source of heating in this region. The distinguishing property of this region is low socioeconomic status of residents: lower educational level of residents and high coal usage for domestic heating during the cold winter season. Region 3 (R3) is in the city center (urban-traffic area) which has the highest population density (18,000 capita km^{-2}) and a busy road network. Measured traffic volume of major roads in this region varies between 10,000–30,000 vehicles day^{-1}. Similar to region 1, educational level of residents is also higher in this region and natural gas is mostly used for domestic heating.

Ambient air monitoring

A preliminary passive sampling campaign for the measurement of ambient O_3, NO_2 and SO_2 was carried out near 65 primary schools to identify the spatial distribution of pollutants between January 9 and 23, 2008. Based on the results

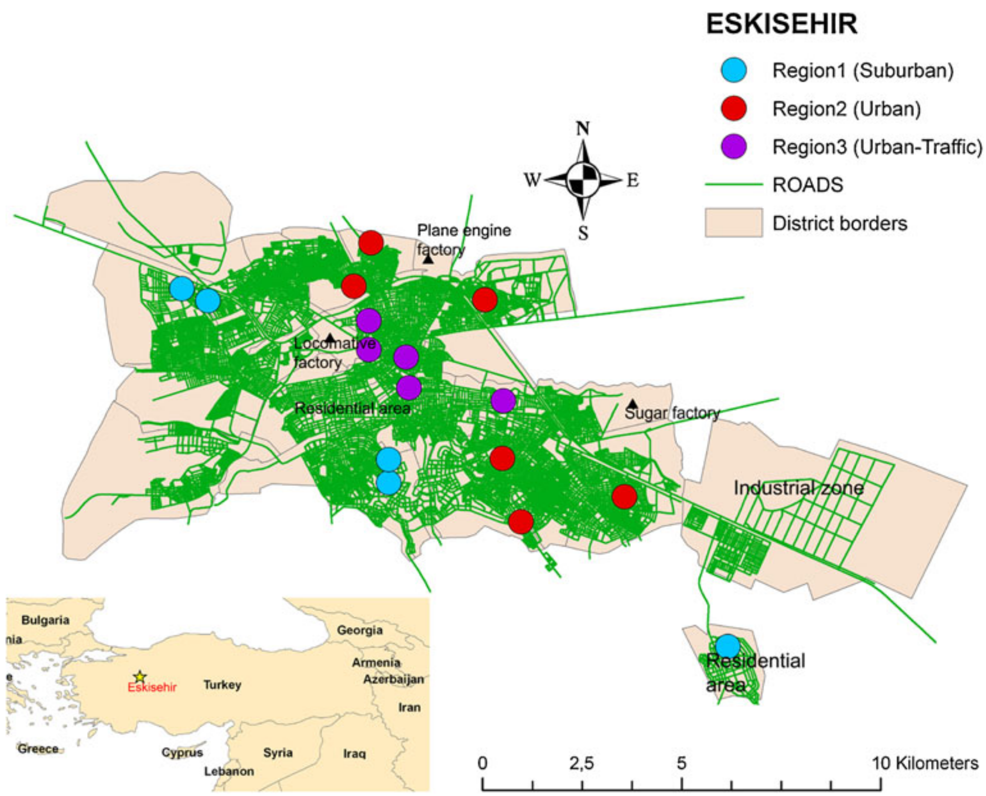

Fig. 1 Location of schools included in the study

of this campaign, polluted/less polluted sites were identified and finally schools for the measurement of lung function parameters were selected (Gaga et al. 2012).

Seasonal exposure level of each child to air pollution was derived from summer (May 27–June 13, 2008) and winter (February 27–March 13, 2009) passive sampling campaigns conducted in the gardens of each selected primary school simultaneously with the lung function tests. For each measurement campaign, two weekly integrated samples were available from each point and air pollution levels during the lung function tests were evaluated by using the average of two sequential weekly average concentrations of ozone (O_3), nitrogen dioxide (NO_2) and sulfur dioxide (SO_2) for each season. Concentrations of $PM_{2.5}$ and PM_{10} were also measured at four monitoring stations during the health survey. The details of the air quality measurements can be found elsewhere (Gaga et al. 2012).

Table 1 shows the summary of seasonal weekly average air pollutant concentrations (microgramme per cubic metre) for the selected regions in the study area. Ozone levels were quite high in region 1. Ozone levels were still high in region 2, but the distinguishing property of this region was higher NO_2 and SO_2 levels in wintertime when compared to region 1. In summer period, none of the measured average pollutant concentrations in R1 were significantly different than R2. In winter period, SO_2 levels were significantly higher in region 2 when compared to other two regions due to high consumption of coal. As NO_2 is a traffic related air pollutant, ambient NO_2 levels were significantly higher in the urban traffic dominated sites of R3, than R1 and R2 for the summer and winter periods. Similarly, ambient O_3 levels were significantly lower in the urban traffic site of R3, than R1 and R2 for the summer and winter periods. Summer and winter period weekly average O_3 concentrations were in the range of 59.6–161.5 and 26.4–133.3 $\mu g\ m^{-3}$, respectively. The pollutant which had the highest variability in the study area was O3. ANOVA test results showed that variation between regions were greater than variation within regions for all pollutants during all sampling campaigns.

Correlation coefficients between weekly average pollutant levels over the study period were calculated. Ozone and NO_2 were significantly negatively correlated with each other both for the summer ($r=-0.382$, $p<0.05$) and winter ($r=-0.801$, $p<0.05$) seasons. This inverse relationship was stronger for the winter season. This is generally caused by the depletion of O_3 by NO in the city center, particularly in areas with high traffic density as the main source of NO_x. O_3 and SO_2 were also significantly negatively correlated ($r=0.395$, $p<0.05$) in the winter season. There was a significantly positive correlation ($r=0.486$, $p<0.05$) between NO_2 and SO_2 for the winter season, probably due to the contribution of emissions from domestic heating.

For each pollutant, correlation coefficients between average concentrations of first and second weeks were calculated for each of the three measurement campaigns. For NO_2, the correlation coefficients were 0.86 ($p<0.0001$), 0.96 ($p<0.0001$) and 0.89 ($p<0.0001$) for preliminary campaign, summer campaign and winter campaign respectively. For SO_2, the correlation coefficients were 0.71 ($p=0.0019$), 0.59

Table 1 Summary of seasonal weekly average air pollutant concentrations (microgramme per cubic metre) for selected regions in the study area (*n* refers to number of data points and two consecutive weekly measurements were carried at out each point for each season)

	Region 1 suburban	Region 2 urban	Region 3 urban traffic	*t* test comparison	*P* value (ANOVA)
Preliminary sampling campaign (January 9–23, 2008)	(n=10)	(n=12)	(n=10)		
O_3	37.6±14.9 (18.8–63.2)	35.2±11.7 (19.8–52.9)	24.0±8.2 (12.3–40.2)	R1 vs. R2 ^{NS} R1 vs. R3* R2 vs. R3*	<0.05
NO_2	22.6±7.8 (9.0–31.5)	28.3±10.9 (11.3–45.7)	43.4±10.9 (24.1–62.5)	R1 vs. R2 ^{NS} R1 vs. R3** R2 vs. R3**	<0.01
SO_2	44.4±4.9 (36.3–51.2)	62.5±13.1 (43.2–88.6)	57.0±10.1 (46.3–73.0)	R1 vs. R2** R1 vs. R3** R2 vs. R3 ^{NS}	<0.01
Summer period (May 27–June 13, 2008)	(n=10)	(n=12)	(n=10)		
O_3	110.0±27.7 (84.2–161.5)	98.4±17.4 (80.5–138.0)	71.8±8.8 (59.6–87.6)	R1 vs. R2^{NS} R1 vs. R3** R2 vs. R3**	<0.01
NO_2	7.3±2.0 (4.7–10.0)	6.9±1.8 (4.7–10.2)	14.2±5.7 (8.5–24.5)	R1 vs. R2^{NS} R1 vs. R3** R2 vs. R3**	<0.01
SO_2	22.3±8.1 (13.5–42.2)	26.7±10.2 (10.9–42.9)	16.5±5.6 (9.3–23.4)	R1 vs. R2^{NS} R1 vs. R3 ^{NS} R2 vs. R3*	<0.05
Winter period (February 27–March 13, 2009)	(n=10)	(n=12)	(n=10)		
O_3	86.7±26.3 (54.2–126.2)	78.6±26.0 (40.7–133.3)	47.7±13.7 (26.4–68.3)	R1 vs. R2^{NS} R1 vs. R3** R2 vs. R3*	<0.01
NO_2	17.6±6.3 (5.6–24.7)	24.4±7.7 (10.8–33.2)	39.9±6.8 (30.8–53.0)	R1 vs. R2* R1 vs. R3** R2 vs. R3**	<0.01
SO_2	55.2±16.6 (18.4–75.8)	76.2±18.9 (55.5–115.9)	57.5±18.2 (21.7–85.7)	R1 vs. R2* R1 vs. R3^{NS} R2 vs. R3*	<0.05

Data given as mean ± standard deviation (minimum–maximum)

R1 region 1, *R2* region 2, *R3* region 3, *NS* not significant by *t* test

*p<0.05, **p<0.01

(p<0.0207) and 0.62 (p=0.0177) for preliminary campaign, summer campaign and winter campaign, respectively. For O_3, the correlation coefficients were 0.95 (p<0.0001), 0.59 (p=0.0196) and 0.69 (p=0.0029) for preliminary campaign, summer campaign and winter campaign, respectively.

Questionnaire

Children aged 9–13 years were examined by the International Study of Asthma and Allergies in Childhood (ISAAC) written questionnaire (ISAAC 1998). The standardized ISAAC questionnaire was directly translated into Turkish without any modifications and no additional validation study was carried out. These questions were used to determine and compare the prevalence of symptoms of asthma, rhinitis and eczema among schoolchildren living in three regions of Eskişehir which have different levels of air pollution. In addition to the ISAAC core questions, additional questions on various environmental risk factors (parental smoking habits at home, coal/wood stove usage at home, having fury domestic pets at home, having molds in the home) were added to the questionnaire. The questionnaires were distributed to children on May 20, 2008, at school to be completed by the parents at home. Information brochures were also sent to each household together with the questionnaires. Participants were given 2 weeks to return the questionnaire back. ISAAC questionnaire was correctly answered by 1,667 (88 %) of 1,880 children.

Lung function test

Each child performed two lung function tests: one for the summer season and one for the winter season. Spirometry tests were performed simultaneously with air quality measurements (summer season: from May 29, 2008 to June 12, 2008 and winter season: from March 2, 2009 to March 17, 2009). Lung function tests were conducted with simultaneous ambient air quality measurements. Lung function measurements included the following flow or volume parameters: forced vital capacity (FVC), forced expiratory volume in 1 s (FEV1), FEV1/FVC%, peak expiratory flow (PEF) and maximal mid-expiratory flow (MMEF). Anthropometric measurements of weight and height were recorded during each lung function test.

Lung function was measured by four pieces of EasyOne spirometers (NDD Medizintechnik, Zurich, Switzerland) and two teams performed in schools. Flow check was done for all spirometers each morning and each evening using a 3.0-l syringe. Lung function testing was performed according to the American Thoracic Society (ATS) protocol (1994). The best trial of the three reproducible maneuvers was selected. Of the 1,880 children, 1,841 and 1,497 completed the lung function tests successfully for the summer and winter evaluations, respectively. Number of children tested decreased about 19 % in winter season as children changed their schools or they were absent in the day of lung function testing.

Predicted lung function values were defined for each child according to the previously developed prediction equations (Hankinson et al. 1999). The term "predicted value" was used to describe the calculated value based on age (in years), height (in centimeters) and gender of each child for the Caucasian ethnic group. Prediction equations used for each lung function parameter were as follows:

For girls:

$$FVCpred\ in\ litres = -1.2082 + 0.05916 \times age + 0.00014815 \times (height)^2 \quad (1)$$

$$FEV1pred\ in\ litres = -0.8710 + 0.06537 \times age + 0.00011496 \times (height)^2 \quad (2)$$

$$PEFpred\ in\ liter\ per\ second = -3.6181 + 0.60644 \times age - 0.016846 \times (age)^2 + 0.00018623 \times (height)^2 \quad (3)$$

$$MMEFpred\ in\ liter\ per\ second = -2.5284 + 0.52490 \times age - 0.015309 \times (age)^2 + 0.00006982 \times (height)^2 \quad (4)$$

For boys:

$$FVCpred\ in\ litres = -0.2584 - 0.20415 \times age + 0.010133 \times (age)^2 + 0.00018642 \times (height)^2 \quad (5)$$

$$FEV1pred\ in\ litres = -0.7453 - 0.04106 \times age + 0.004477 \times (age)^2 + 0.00014098 \times (height)^2 \quad (6)$$

$$PEFpred\ in\ liter\ per\ second = -0.5962 - 0.12357 \times age + 0.013135 \times (age)^2 + 0.00024962 \times (height)^2 \quad (7)$$

$$MMEFpred\ in\ liter\ per\ second = -1.0863 + 0.13939 \times age + 0.00010345 \times (height)^2 \quad (8)$$

Lung function test results for each child were compared to predicted values determined according to the Eqs. 1–8. Values obtained for FVC, FEV_1, PEF and MMEF were expressed as percentages of predicted values. The child was decided to have normal lung function if he/she had the following criteria: FVC ≥85 % of predicted and FEV_1 ≥85 % of predicted and PEF ≥75 % of predicted and MMEF ≥75 % of predicted. If any of these criteria was not met, we decided that child had impaired lung function. These criteria were selected based on the methodology from former studies (Raizenne et al. 1996; Langkulsen et al. 2006; Moshammer et al. 2006; Slachtova et al. 2011).

Statistical analysis

Health effects of air pollution (based on residential area and measured air pollutant concentrations) were estimated by multivariate logistic regression analyses. This technique was used to assess the independent effect of air pollution on the prevalence of current symptoms and impaired lung function. We focused three symptoms in multivariate logistic regression analyses: current wheeze (“Has your child had wheezing or whistling in the chest in the past 12 months?”), current rhinoconjunctivitis (“In the past 12 months, has your child had a problem with sneezing, or a runny, or blocked nose when he/she did not have a cold or the flu?” and “In the past 12 months, has this nose problem been accompanied by itchy-watery eyes?”) and current itchy rash (“Has your child had this itchy rash at any time in the past 12 months?”). The strength of the relationship between risk factors and symptoms was evaluated by calculating adjusted odds ratio (OR) and their 95 % confidence intervals (CI) for the factors tested. Independent variables included in the analysis were responder of the questionnaire (mother =1, father or others=2), gender (female=1, male=2), age (years), parental smoking habits (exposed=1, not exposed=2), coal or wood stove usage (yes=1, no=2), maximal parental education of the family (<=8 years=1, >8 years=2), having domestic pets (yes=1, no=2) and molds in the home (yes=1, no=2). In addition to multivariate logistic regression analyses, differences between study groups were assessed by chi-square (χ^2) test, one-way analysis of variance (ANOVA) and independent samples t tests. A p value of <0.05 was considered statistically significant. The data were analyzed using the statistical software SAS version 9.2

Results

General characteristics of the population

Primary school children in the fourth and fifth grade were selected as the target population of the study. The baseline characteristics of schoolchildren by region are presented in Table 2. Almost half of the children were girls. The average age of schoolchildren included in the study was 10.5± 0.6 years. The study included children between 9 and 13 years, although 99 % of the total population was in the age group of 10–11 years. Age and height of children seemed to vary significantly among three regions although the distributions were narrow. The average age of children living in region 1 were 1–2 months greater than the children from the other two groups. On the other side, children living in region 2 were significantly shorter (around 3 cm) than the other two groups. The children were comparable with respect to gender, responder of the questionnaire and parental smoking habits ($p>0.05$). Questionnaires were mostly answered by the mothers (67.9 %). More than half of the children lived with one or more smokers in their homes (52.3 %). Children living in region 2 had quite low parental education than that of other two groups ($p<0.05$) and use of coal/wood stoves for domestic heating was used more wide spread in this region. Lower income families tend to use coal/wood stoves in Turkey as natural gas prices are quite high when compared to coal/wood. Data for parental education and coal combustion were used as proxy for socioeconomic status in this study: region 2 was defined as the low socioeconomic status region according to these variables.

Health survey

Table 3 shows the prevalence of respiratory symptoms based on the ISAAC questionnaire. The prevalences for ever had asthma, wheezing, hay fever, rhinoconjunctivitis and eczema were reported as 7.1, 10.7, 30.6, 42.2 and 4.8 %, respectively. There were no significant difference for the prevalence of ever had asthma, hay fever and eczema among

Table 2 Characteristics of schoolchildren included in the analysis (n=1,880)

Characteristics	Region 1 (n=532)	Region 2 (n=582)	Region 3 (n=766)	p value (ANOVA)
Mean age ± SD (years)	10.6±0.6	10.5±0.6	10.5±0.6	<0.01
Mean height ± SD (cm)[a]	141±7	138±7	141±7	<0.01
Characteristics	Region 1 (n=532)	Region 2 (n=582)	Region 3 (n=766)	p value (χ^2)
Gender [n (female %)]	253 (48)	287 (49)	390 (51)	0.53
Mother responder [n (%)]	274 (70)	340 (64)	495 (70)	0.10
Parental smoking habits [n (%)][b]	215 (53)	291 (56)	356 (50)	0.08
Maximum parental education [n (%)][c]	304 (73)	115 (22)	506 (70)	<0.01
Coal/wood stove usage [n (%)]	13 (3)	368 (75)	96(14)	<0.01
Domestic pets [n (%)]	47 (12)	85 (17)	74 (11)	<0.01
Molds in the home [n (%)]	74 (18)	138 (27)	79 (11)	<0.01

SD standard deviation

[a] Measured at initial (summer period) lung function test

[b] At least one person smokes in the child’s home

[c] Education of 8 years or more

Table 3 Number and prevalence (percent) of symptoms by region according to ISAAC written questionnaire (n=1,667)

Symptom	Region 1 (n=416)	Region 2 (n=532)	Region 3 (n=719)	p value (χ^2)
Current wheezing/whistling	41 (10)	66 (13)	38 (5)	<0.01
Current wheezing during/after exercise	31 (8)	78 (15)	51 (7)	<0.01
Current cough at night	149 (37)	206 (39)	223 (31)	0.01
Asthma ever	36 (9)	36 (7)	46 (6)	0.35
Wheezing/whistling ever	45 (11)	76 (15)	58 (8)	<0.01
Current rhinoconjunctivitis	127 (32)	206 (41)	204 (30)	<0.01
Current rhinoconjunctivitis with itchy-watery eyes	71 (19)	96 (20)	98 (15)	0.05
Hay fever ever	126 (31)	144 (28)	224 (32)	0.30
Rhinoconjunctivitis ever	169 (41)	263 (50)	271 (38)	<0.01
Current itchy rash	35 (9)	43 (8)	41 (6)	0.15
Eczema ever	17 (4)	34 (7)	28 (4)	0.10
Chronic rash ever	42 (10)	66 (13)	56 (8)	0.03

Results are expressed as number of affected children with the percentage in parentheses. "Current" symptoms referred symptoms in the past 12 months

regions however prevalences of ever had wheezing and rhinoconjunctivitis were significantly higher among children living in region 2 when compared to those living in other two regions. The prevalences of all current symptoms, except for current itchy rash, were also systematically higher in region 2. In general, it was observed that most of the symptoms were most prevalent in region 2 even if the difference was not significant for all symptoms. It was striking that report of "ever had hay fever" were less frequent in region 2 although "rhinoconjunctivitis ever" was significantly more frequent in the same region. The reason for the possible underestimation of hay fever prevalence might be because of the incorrect perception of the term "hay fever" in region 2 which was the less educated among three regions. Rhinoconjunctivitis was probably less frequently termed "hay fever" in this less educated neighbourhood. The cumulative prevalences of asthma, hay fever and eczema might have been under-diagnosed in region 2 due to less medical check-up because of parents' low income and low educational levels.

Table 4 gives the measured lung function values for summer and winter season evaluations. Measured lung function levels of children living in region 2 were lowest among the three regions both for the summer and winter seasons. As it was explained earlier, region 2 is a low socioeconomic status region and those children living in region 2 were significantly shorter than the others. Therefore, it was an expected result that these children had lower measured lung function values in accordance with their body height. Table 5 gives the lung function values expressed as percentage of predicted value adjusted for height and gender for each region. When compared with predicted values according to height and gender, children living in region 1 had significantly lower average percentage of predicted FVC and FEV_1 values only for the summer season when compared to other regions. As it was expressed before, region 1 was far away from the city center with quite high ozone levels. Measured lung function levels, except for PEF, of children living in region 2 were most compatible with the predicted lung function levels.

Table 4 Measured values of lung function parameters by region

Lung function parameter	Region 1	Region 2	Region 3	P value (ANOVA)
Summer period (n=1,841)	n=519	n=571	n=751	
FVC (L)	2.29±0.46	2.24±0.39	2.30±0.4	0.01
FEV1 (L)	1.95±0.35	1.90±0.32	1.96±0.34	<0.01
PEF (L/s)	4.13±0.89	3.94±0.88	4.14±0.92	<0.01
MMEF (L/s)	2.32±0.69	2.21±0.68	2.31±0.66	0.02
Winter period (n=1,497)	n=413	n=465	n=619	
FVC (L)	2.57±0.47	2.49±0.46	2.56±0.48	0.01
FEV1 (L)	2.14±0.35	2.08±0.37	2.15±0.34	<0.01
PEF (L/s)	4.67±0.89	4.45±0.96	4.68±0.92	<0.01
MMEF (L/s)	2.37±0.77	2.33±0.79	2.42±0.69	0.15

FVC forced vital capacity, *FEV_1* forced expiratory volume in 1 s, *PEF* peak expiratory flow, *MMEF* maximal mid-expiratory flow

Table 5 Lung function values expressed as percentage of predicted value by region

	Region 1	Region 2	Region 3	*p* value (ANOVA)
Summer period (n=1,841)	(n=519)	(n=571)	(n=751)	
FVC—% of predicted value	95.4±14.7	99.9±15.7	97.2±14.3	<0.01
FEV1—% of predicted value	92.0±12.5	95.1±13.6	93.6±12.2	<0.01
PEF—% of predicted value	90.0±17.5	90.1 ±18.5	91.3±17.8	0.35
MMEF—% of predicted value	89.9±26.3	89.5±26.6	90.5±24.0	0.74
Winter period (n=1,497)	(n=413)	(n=465)	(n=619)	
FVC—% of predicted value	97.2±12.7	99.0±14.7	97.3±12.3	0.07
FEV1—% of predicted value	91.8±10.6	92.8±11.6	92.7±10.2	0.35
PEF—% of predicted value	93.4±15.5	91.7±17.2	94.0±16.2	0.07
MMEF—% of predicted value	84.2±26.2	85.3±26.9	87.1±23.2	0.21

Analyses with multiple variables

Table 6 shows the multivariate logistic regression analysis results. Children with normal lung function in the summer season were less observed in region 1 when compared to region 3 [OR=1.33 (95 % CI 1.01–1.75)] and female gender was associated with impaired lung function in summer season, whereas other factors were not associated. When multivariate logistic regression analyses were carried out for girls and boys separately, it was found that girls with impaired lung function (only for the summer season evaluation) were more observed in higher concentration ozone areas (R1 and R2) when compared to urban-traffic area (R3) with the lowest concentration of ozone. Adjusted odds ratios and 95 % confidence interval were calculated as OR= 1.49 (95 % CI 1.04–2.14) and OR=1.69 (95 % CI 1.06–2.71) for R1 vs. R3 and R2 vs. R3, respectively. This association was not found for the winter season. The prevalence of impaired lung function in boys didn't vary significantly among three regions.

The prevalence and symptoms of current wheeze and current rhinoconjunctivitis did not vary significantly among three regions. Prevalence of current itchy rash was more observed in suburban area (region 1) when compared to urban-traffic area (region 3) [OR=1.72 (95 % CI 1.03–2.87)]. Living in a moldy home was positively associated with the prevalence and symptoms of current wheeze, current rhinoconjunctivitis and current itchy rash ([OR: 2.49, (95 %CI 1.68–3.70)]; [OR: 1.57, (95 %CI 1.16–2.14] and [OR: 1.68, (95 %CI 1.03–2.74)], respectively). No association was found between molds in the home and impaired lung function. Children whose mothers answered the questionnaire reported higher prevalences of current rhinoconjunctivitis and current itchy rash. Low parental education and having domestic fury pets were positively associated with the prevalence of symptoms of current rhinoconjunctivitis. Age, gender, parental smoking and coal or wood stove usage were not associated with any of the symptoms. Gender was not associated with any current symptoms. As we worked on a narrow age range (99 % of the total population was between 10 and 11), no association was found with age and any of the investigated health outcomes.

The results of the multivariate logistic regression analyses for single pollutant models adjusted for potential confounders are shown in Table 7. Association of each pollutant with impaired lung function and symptoms were investigated for girls and boys separately. A significant positive association between impaired lung function and 2-weeks average ozone concentrations was found for the summertime evaluation only for the girls. A 10 μg m^{-3} increment in 2-weeks average summertime ambient ozone concentration was associated with a 11.1 % increment in the prevalence of girls having impaired lung function [OR=1.11 (95 % CI 1.03–1.19), $p<.05$]. This association was examined using two-pollutant regression models (Table 8). The association between impaired lung function and summer time ozone concentrations was consistent in analyses with two pollutants. There were no associations between pollutant levels and impaired lung function for the winter period both for the single-pollutant models and multi-pollutant-models, neither for girls nor for boys. No association was found between any of the measured air pollutants and symptoms of current wheeze, current rhinoconjunctivitis and current itchy rash in single pollutant multivariate logistic regression analyses.

Discussion

A significant reduction in lung function among girls was associated with increasing average O_3 levels measured for a 2-weeks period in summer season. From previous epidemiological studies it is consistent that short-term O_3 exposure causes a decrease in children's lung function parameters such as FVC, FEV1 and PEF (Brunekreef et al. 1995; Jalaludin et al. 2000). Current study produced results which corroborate the findings of those previous works. Some studies also suggest that long-term exposure to ozone reduces lung function growth in children (Peters et al.

Table 6 Multivariate logistic regression analyses for the association between independent variables, any of the symptoms and impaired lung function among school children in Eskisehir

Independent variables		Impaired lung function summer OR (95 % CI) *n*=1,380	Impaired lung function winter OR (95 % CI) *n*=1,118	Current wheeze OR (95 % CI) *n*=1,366	Current rhinoconjunctivitis with itchy watery eyes OR (95 % CI) *n*=1,334	Current itchy rash OR (95 % CI) *n*=1,330
Region	R1 vs R3	1.33 (1.01–1.75)	1.25 (0.93–1.68)	1.12 (0.69–1.81)	1.05 (0.78–1.42)	1.72 (1.03–2.87)
	R2 vs R3	1.20 (0.86–1.67)	1.23 (0.85–1.77)	1.35 (0.80–2.28)	1.26 (0.89–1.79)	1.02 (0.52–1.99)
Responder of the questionnaire	Mother vs father	–	–	1.34 (0.89–1.99)	1.40 (1.08–1.81)	2.13 (1.25–3.63)
Age (years)		1.10 (0.92–1.32)	1.02 (0.84–1.24)	1.25 (0.95–1.66)	1.08 (0.89–1.30)	1.14 (0.81–1.59)
Gender	Girls ve boys	2.08 (1.67–2.59)	1.21 (0.95–1.53)	0.78(0.55–1.11)	1.05 (0.83–1.32)	0.73 (0.48–1.11)
Maximum parental education	Low education vs. high education	1.06 (0.82–1.36)	0.92 (0.70–1.22)	1.26(0.84–1.91)	1.43 (1.10–1.87)	1.17 (0.72–1.90)
Parental smoking habits	Yes vs. no	1.18 (0.95–1.48)	1.03 (0.81–1.31)	1.36(0.94–1.96)	1.22 (0.97–1.55)	1.10 (0.72–1.69)
Coal or wood stove usage		1.07 (0.77–1.48)	1.00 (0.70–1.43)	1.29(0.78–2.13)	1.18 (0.84–1.66)	1.12 (0.59–2.15)
Molds in the home	Yes vs. no	0.84 (0.63–1.13)	0.88 (0.63–1.22)	2.49(1.68–3.70)	1.57 (1.16–2.14)	1.68 (1.03–2.74)
Domestic pet ownership	Yes vs. no	0.67 (0.48–0.94)	0.93 (0.65–1.33)	1.50(0.93–2.41)	1.63 (1.16–2.30)	1.45 (0.81–2.59)

OR odds ratio, *CI* confidence interval

1999; WHO 2003). Our air quality measurements were only available for a limited time period (2 weeks) in winter and summer; it may not be representative of seasonal means. However, geographic coverage of air quality measurements was good as we had simultaneous measurement data for 16 points in a study area of around 100 km^2.

No association was found between any of the measured air pollutants and any symptoms of current wheeze, current rhinoconjunctivitis and current itchy rash. On the other side, prevalence of current itchy rash was more observed in suburban area when compared to urban-traffic area [OR= 1.72 (95 % CI 1.03–2.87)]. Short-term (Hoek et al. 1993; Gielen et al. 1997; Burnett et al. 2001) and long-term (Ramadour et al. 2000; Akinbami et al. 2010) exposure to ambient ozone has been linked to development and exacerbation of childhood asthma and wheezing previous studies. The effect of outdoor or indoor air pollution on current rhinoconjunctivitis is inconsistent (Brunekreef and Sunyer 2003). There is increasing evidence on adverse effects of air pollutants on current itchy rash (Lee et al. 2008; Brunekreef et al. 2009).

The association between impaired lung function and ozone levels was found only for girls. Many previous studies reported that girls are affected from air pollutants more than boys (Brunekreef et al. 1997; Peters et al. 1999; Frye et al. 2003; Rojas-Martinez et al. 2007; Oftedal et al. 2008; Liu and Zhang 2009). A former study from South California investigating long-term effects reported that lung function level was lower in communities with higher O_3 average levels, particularly among girls with asthma and spending more time outdoors (Peters et al. 1999).

An association between ozone and impaired lung function was found only for the summer season evaluation. Ambient ozone levels are highest in the summertime due to increasing photochemical reactions in the atmosphere. Also, it is well-known that people spend more time outdoors in summer season compared to winter. Both higher ozone levels and spending more time outdoors in summertime would probably made it easier in our study to see the association between impaired lung function and ambient ozone concentrations. As exposure to ambient air pollutants is related not only to the measured concentration levels but also to the time spent outdoors, pollution may affect children more if they stayed outdoors longer (Peters et al. 1999; Gauderman et al. 2000; Langkulsen et al. 2006).

Previous studies reported that studying the health effects of ozone might be more difficult in the presence of co-pollutants such as particulate matter (Uysal and Schapira 2003). Although particulate matter ($PM_{2.5}$ and PM_{10}) levels were measured during the study period, we did not include PM data into analysis as we did not have school-based measurements. Daily particulate matter concentrations were measured simultaneously with the lung function measurements at four sampling stations in the study area. PM_{10}

Table 7 Multivariate logistic regression analyses for impaired lung function and current symptoms for 10 μg m^{-3} increment of each air pollutant concentration after adjustment for potential confounders (single pollutant model)

		Impaired lung function[a] OR (95 % CI)	Current wheeze OR (95 % CI)	Current rhinoconjunctivitis OR (95 % CI)	Current itchy rash OR (95 % CI)
Girls		n=731 (summer) n=588 (winter)	n=722	n=705	n=704
O_3	Summer	1.11 (1.03–1.19)*	0.95 (0.83–1.08)	1.09 (0.99–1.20)	1.01 (0.87–1.17)
	Winter	1.03 (0.96–1.11)	0.92 (0.82–1.04)	1.05 (0.96–1.15)	0.98 (0.86–1.13)
NO_2	Summer	0.79 (0.59–1.06)	0.92 (0.53–1.60)	0.84 (0.55–1.29)	0.48 (0.22–1.03)
	Winter	0.97 (0.84–1.11)	1.02 (0.81–1.28)	0.89 (0.75–1.06)	1.91 (0.70–1.18)
SO_2	Summer	1.08 (0.88–1.34)	0.77 (0.54–1.11)	1.09 (0.83–1.45)	0.98 (0.64–1.49)
	Winter	1.00 (0.90–1.11)	1.08 (0.91–1.29)	0.97 (0.85–1.10)	1.07 (0.87–1.31)
Boys		n=649 (summer) n=530 (winter)	n=640	n=623	n=624
O_3	Summer	1.02 (0.93–1.10)	1.08 (0.95–1.23)	1.02 (0.91–1.15)	1.09 (0.94–1.26)
	Winter	1.03 (0.95–1.11)	1.04 (0.93–1.16)	1.08 (0.97–1.19)	1.07 (0.94–1.22)
NO_2	Summer	1.23 (0.88–1.71)	0.66 (0.35–1.23)	0.87 (0.52–1.44)	0.84 (0.44–1.60)
	Winter	0.98 (0.84–1.14)	0.88 (0.70–1.09)	0.87 (0.71–1.06)	0.89 (0.69–1.14)
SO_2	Summer	0.93 (0.75–1.15)	1.15 (0.84–1.58)	1.21 (0.90–1.62)	1.18 (0.81–1.74)
	Winter	0.93 (0.83–1.05)	1.00 (0.85–1.18)	1.01 (0.87–1.17)	0.91 (0.75–1.09)

The dependent variables were adjusted for responder of the questionnaire (for questionnaire data only, not used for impaired lung function), age, parental smoking habits, coal or wood stove usage, maximum parental education, domestic pet ownership and molds in the home

OR odds ratio, *CI* confidence interval

*p value<0.05

[a] Criteria for impaired lung function from spirometry test; FEV1 <85 % predicted and FVC <85 % predicted and PEF <75 % and MMEF <75 % predicted

levels exceeded the EU limit value of 50 μg m^{-3} (daily limit that should not to be exceeded more than 35 days in a year) at each station almost every day during the sampling period. Percent exceedances of PM_{10} levels were in the range of 77–100 % in both seasons. $PM_{2.5}/PM_{10}$ ratios increased in the winter period samples in all four sampling locations. Winter to summer ratios of measured $PM_{2.5}$ concentrations increased about two times in all four sampling stations. Concentrations of $PM_{2.5}$ and PM_{10} were present in much higher concentrations in the urban-traffic sampling station as compared to other locations. The details of the air quality measurements can be found elsewhere (Gaga et al. 2012).

We found higher frequencies of current symptoms, except for current itchy rash, for children living in region 2. Also, doctor diagnosed diseases were probably underestimated in this low SES region. In addition, measured

Table 8 Two pollutant multivariate logistic regression analyses only for girls for impaired lung function in the summer period (n=731)

	Impaired lung function[a]		
	Adjustment pollutant		
Main pollutant	O_3	NO_2	SO_2
O_3	1.11 (1.03–1.19)[b]*	1.10 (1.02–1.21)*	1.11 (1.03–1.19)*
NO_2	0.99 (0.71–1.40)	0.79 (0.59–1.06)[b]	0.80 (0.60–1.08)
SO_2	1.03 (0.84–1.28)	1.05 (0.85–1.30)	1.08 (0.88–1.34)[b]

Each row gives odds ratios and confidence intervals OR (95 % CI) for the indicated pollutant, after adjustment for the pollutant listed at the top of the column. The dependent variables were adjusted for age, parental smoking habits, coal or wood stove usage, maximum parental education, domestic pet ownership and molds in the home

[a] Impaired lung function for summertime study period vs. pollutant levels for summertime study period

[b] These odds ratios and confidence intervals are from the single-pollutant models given in Table 7

*p value <0.05

unadjusted lung function levels were lower for those children, but this was because the children in this area were also shorter. Lower SES, presence of more indoor allergens (molds and pets etc.) at home and air pollution were likely responsible for the symptom results. Children in R2 were shorter for their age than in the other areas. We can only speculate about a role of air pollution as very few studies have addressed this outside the context of indoor biomass combustion (Mishra and Retherford 2007; Samet and Tielsch 2007). The exception is a recent study from Peru (Harris et al. 2011) which in our view requires further corroboration.

Our ISAAC-written questionnaire results determined the rate of ever had asthma, wheezing, hay fever, rhinoconjunctivitis and eczema as 7.1, 10.7, 30.6, 42.2 and 4.8 %, respectively. We found only one previous study from the same region (Eskisehir) including 2,358 school children (aged 10–12 years) which reported the cumulative prevalences of asthma (diagnosis by doctor), wheezing ever, rhinoconjuctivitis ever and eczema (ever diagnosed by doctor) as 2.2, 18.4, 36.0 and 3.0 %, respectively (Metintaş et al. 2001). Although this study did not use the ISAAC protocol, their results were comparable with ours and all symptoms, except for wheezing ever, were increased over time.

Our study determined the current prevalences of wheezing, rhinoconjunctivitis and eczema as 8.7, 32.2 and 7.1 %, respectively. According to a recent multi-centric ISAAC study from Turkey, the current prevalences of wheezing, rhinoconjunctivitis, and eczema in 6,963 school children (aged 9–11) were 15.8, 23.5 and 8.1 %, respectively (Civelek et al. 2010a). Another multi-centric (including Eskisehir) study including 11,081 school children (aged 10–12) from Turkey reported the current prevalences of wheezing, rhinitis and eczema as 10.0, 15.6 and 4.1 %, respectively, for children living in urban areas, and 11.2, 20.8 and 6.6 %, respectively, for children living in rural areas (Kurt et al. 2007). It should be noted that this study also did not use the ISAAC questionnaire and we were restricted to making comparisons with studies using other protocols.

The prevalence of rhinitis-related symptoms estimated in our study were among the highest when compared to various previous studies from Turkey. Our study determined the prevalences of hay fever ever, rhinoconjunctivitis ever and current rhinoconjunctivitis as 30.6, 42.2 and 32.2 %, respectively. An ISAAC study including around 2,500 school children aged 6–12 years from İstanbul (Turkey) reported the prevalence for physician-diagnosed rhinitis, lifetime rhinitis and current rhinitis and as 7.9, 44.3 and 28.9 %, respectively (Tamay et al. 2007). Another ISAAC study including 6,963 elementary school children aged 9–11 years reported the prevalence of physician-diagnosed rhinitis, ever rhinitis, current rhinitis, and current rhinoconjunctivitis as 31.0, 51.6, 43.5 and 23.1 %, respectively (Civelek et al. 2010b). Our results were in accordance with these findings.

Conclusions

The results of this study showed that increasing ozone concentrations in summertime may cause a sub-acute impairment in school aged children's lung function, especially for girls. Since air quality measurements were carried out for a limited time period (2 weeks in summer and winter); weekly averages in winter and summer period may not represent the whole year seasonal averages. Air quality measurements for longer duration are needed in order to give more representative results. Variability in measured air pollutant levels was not very strong in our study, neither within region nor between regions. This may be the reason for a lack of association between measured air pollutant levels and health outcomes other than impaired lung function.

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