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Neighborhood Air Quality and Snoring Among In School-Aged Children.

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Take Home Message: Environmental pollution emerges as an important and modifiable contributor to the prevalence of habitual snoring in school-aged children.

Abstract:

Background: The prevalence of habitual snoring (HS) has been extensively explored in pediatric populations. Although exposure to cigarette smoke increases the risk of HS in a dose-dependent fashion, the potential contribution of air quality to HS remains unclear.

Methods: 6,000 questionnaires were distributed to 6-12-year-old children attending public schools in 5 distinct neighborhoods within the city of Tehran that were pre-selected based on air quality measures. HS was defined as loud snoring ≥ 3 nights/week. Information regarding clinically- and family-related HS risk factors was also obtained. Descriptive statistics followed by adjusted risk assessments were conducted.

Results: Among the 4,322 completed datasets (72%), the prevalence of HS was 11.6%. Partition of HS rates according to air quality neighborhood characteristics revealed significantly higher HS frequencies among children residing in neighborhoods with greatest pollution (24.5 % and 12.1% in South and Central neighborhoods vs. 7.0% and 7.7%.in North and East neighborhoods, respectively). The regional variance in HS was primarily accounted for by an integrated measure of air quality, even after controlling for other risk factors.

Conclusions: Environmental air quality emerges as a significant and potentially modifiable contributor to the risk for developing HS during childhood.

Introduction

Snoring in school-aged children is a frequent occurrence that not only illustrates the presence of increased upper airway resistance during sleep, but is also one of the major symptoms of obstructive sleep apnea (OSA). A large number of studies have thus far evaluated the prevalence of habitual snoring (HS) in pediatric populations all over the world. Based on variable definitions used for HS, the prevalence of HS ranged from 2.5% to more than 20% of all children, with a median of 10-12% (1-9). Independently, HS has been strongly and independently associated with behavioral hyperactivity, learning and behavioral problems, restless sleep, and poor academic performance, even in the absence of OSA (4, 7, 8, 9-11). Furthermore, HS has also been linked to an increased risk of elevated systemic blood pressure and nocturnal enuresis (12, 13).

The major risk factors enumerated for the presence HS include a positive family history of snoring, prematurity, obesity, ethnic characteristics, early life history of RSV bronchiolitis, lower socioeconomic status, allergies, asthma, and passive exposure to cigarette smoke (1-11, 14-18). More specifically, exposure to cigarette smoke increased the risk of habitual snoring in a dose-dependent fashion, such that the highest prevalence was found when both parents smoked (1, 18-21). However, the impact of environmental pollution on HS has not been extensively assessed . Zhang and colleagues reported that nitrogen dioxide (NO_2) levels inside the home were higher in children who habitually snored (22), and similar findings have been recently reported regarding ambient particulate matter exposures in adults (23). In addition, we recently reported that exposure to increased biomass indoor pollution is associated with an inordinately elevated prevalence of HS in children living in developing regions of Peru (24). We should further emphasize that long-term exposure to air pollutants has been associated with increased risk of many respiratory illnesses in children, such as allergies, asthma, and respiratory infections with potentially long-term adverse implications (25).

Despite the fact that air quality in most cities within the developed world has been subjected to stringent monitoring and standards for motor vehicle and industrial emissions, air pollution is still a major issue in the vast majority of metropolitan areas. Substantial concerns on the long-term effects of sustained exposures to different air pollutants such as particulate matters ($PM_{2.5}$ and PM_{10}), ozone (O_3), sulfur dioxide (SO_2), nitrous oxides (NOx), and carbon monoxide (CO) have been raised in large-cohort studies (26, 27).

Based on aforementioned considerations, this study was designed to examine the potential associations between HS and exposure to air pollutants in a large metropolitan environment with unique topographical characteristics, namely the city of Tehran. The major hypothesis of the present study was that the prevalence of HS in children living in neighborhoods that exhibit higher air pollution levels would be higher than in those with lesser air pollution.

Methods

Study design and population: The study was approved by Institutional Ethics Board of the Iran University of Medical Sciences and by the University of Louisville Human Research Committee (protocol #474.99). A total of 6,000 validated questionnaires (9, 28, 29) were distributed during a period of 3 months during late 2007 and early 2008. 1,800 of the children invited to participate were between the ages of 5-7 years and the remaining 4,200 children were 8-12 years old. All children attended public schools in 5 distinct districts within the city of Tehran during the data collection period.

The 5 districts were selected based on the officially published air quality measures by the governmental Air Pollution Control Company (AQCC) corresponding to the 4 cardinal directions (N, S, E, W) and the central district of the city (C). The city of Tehran is divided into 22 districts, with different elevations and socioeconomic status. In order to achieve the maximum distinction between neighborhoods, two imaginary lines crossing each other with the right angle at the center of the city were drawn and the 4 cardinal direction districts as well as one central district were selected (Figure 1; Table 1). From each district, 4 public schools were randomly selected for distribution of the questionnaires.

Exposure Assessments - Air Pollution: In Tehran, the air monitoring stations are operated by AQCC and routinely measure several major pollutants: PM_{10} (particles less than 10 microns in aerodynamic diameter), sulfur dioxide (SO_2), nitrogen dioxide (NO_2), carbon monoxide (CO), and ozone (O_3). The quality of air in these 5 regions was determined by the Pollutant Standards Index (PSI) which included values for these 5 air pollutants measured on a daily basis in stations located within the selected regions during the years 2006-2007 (Figure 1). The analytical monitors in each station are fully automated, and also include a daily automated calibration system. Once a year, the stations conduct quality control and quality assurance tests. PM_{10} was measured by Verewa Extractive Beta Gauge Particulate Monitor (Durag Inc. USA, Model F-701); sulfur dioxide is measured by Fluorescence SO_2 analyzer (Thermo Environmental Instruments Inc. USA, Model 43C); nitrogen dioxide by Chemiluminescence NO-NO2-NOx analyzer (Thermo Environmental Instruments Inc. USA, Model 42C); ozone by U.V. Photometric O_3 Analyzer (Thermo Environmental Instruments Inc. USA, Model 49C); and carbon monoxide by Gas Filter Correlation (GFC) CO Analyzer (Thermo Environmental Instruments Inc. USA, Model 48C).

Questionnaire: The questionnaire used in this study was based on a previously validated questionnaire (9, 28, 29). The questionnaire was translated into Farsi, and then independently retranslated back to English, to ascertain that no changes in the content and meaning of each question occurred. Parents of the children invited to participate received the questionnaire which included questions regarding family history of snoring, parental smoking habits, child's past medical history and current use of medications, as well as information regarding allergies, asthma, previous adenotonsillectomy (T&A), recurrent ear infections, ear tube placement. Habitual snoring (HS) was defined as loud snoring $\geq$ 3 nights/ week.

Data analysis: Descriptive analyses were employed to summarize the attributes and characteristics of the subjects based on snoring. To examine associations between potential risk factors and HS clusters multivariable logistic regression models were used. The main approach consisted of comparisons between HS and all others. In addition to age and gender, the following variables were considered for inclusion in the models. 1) Environmental exposures: including parental smoking (none, one parent, both parents), number of siblings, and neighborhood of residence. 2) Socioeconomic factors: including paternal and maternal education (primary school, middle school, high school, university), presence of overcrowding (>1 person/room–1). 3) Clinical features and symptoms: including child history of atopic disease, upper and lower respiratory symptoms in the child, prevalence and frequency of wheeze, chronic cough, recurrent ear infections, adenotonsillectomy (yes/no), placement of tympanostomy tubes (yes/no).

To explore potential causal pathways in our data, we developed 3 logistic regression models with incremental complexity. First, we generated a simple model that was adjusted only for age and sex. Then, a second model was adjusted for all familial risk factors, and the third model was adjusted for other clinical features. Finally, a model was constructed by adjusting for environmental and clinical conditions simultaneously, i.e., a fully adjusted model. All variables associated with prevalence of HS ($p<0.05$) in one model were included in the next modeling steps, except when the information contained in two or more variables was so similar (co-linear) that only one could be taken into the next modeling step. For example, these circumstances became applicable in the case of paternal and maternal education, current parental smoking and home crowding. Findings are described as risk ratios (RR) with 95% confidence intervals (95% CI). We calculated the population-attributable risk fraction, which corresponds to the proportion of HS that could be prevented assuming causality of the associations and elimination of the risk factors, by using the aflogit command in STATA (30) on the logistic regression framework, since such approach enables taking into account potential confounders.

Results

The response rate was 72% corresponding to a total of 4,322 questionnaires that were duly completed parents and returned to the investigators .The prevalence of HS was similar for boys and girls from ages 6 -10 years (Figure 2). However, boys had significantly higher prevalence of habitual snoring at ages 11-12 years (Figure 2; p<0.01). Age related declines in the frequency of HS occurred, especially at ages 9 and older (Figure 3). As such the prevalence of HS in the 6-8 year-old children was significantly higher than at older ages (10-12 years; Figure 3; p<0.00001).

In the bivariate analyses, the prevalence of HS was increased if allergic rhinitis, recurrent ear infections, asthma, tympanostomy tubes, previous adenotonsillectomy (T&A) were also reported (Tables 2 and 3). In addition, HS was more likely if a positive history of parental smoking, or snoring was present (Table 3).

Partition of HS rates according to air quality neighborhood characteristics revealed that the frequency of HS was significantly higher among children residing in the neighborhoods with poorest air quality when compared to the neighborhoods with lowest degree of air pollution (24.5 % vs. 7.2%;; RR: 3.49; 95% CI: 2.67-6.69; p<0.0001). The increasing risk effects of air pollution, although present for other respiratory symptoms such as asthma (RR: 1.86; 95% CI: 1.22-3.14; p<0.01), were not as pronounced as those identified for HS. The regional variance in the frequency of children fulfilling the criteria for HS was accounted for by the reported corresponding neighborhood air quality indicators, even after controlling for all other risk factors delineated in Table 2 (RR: 1.94; 95% CI: 1.57-2.63; $p<0.001$; Table 3). Therefore, rather than include each of the air pollutants separately, we included either neighborhood as the surrogate reporter of pollution levels or global Pollutant Standards Index (PSI) "non-healthy days", since both yielded comparable findings.

In the initial model adjusted only for age and gender, there was a robust effect of neighborhood location or PSI "non-healthy day" group on the risk of snoring frequency in our cohort (RR: 3.46; 95% CI: 2.66-7.19, $P<0.0001$).Based on the bivariate significant associations between HS and clinical history elements (i.e., allergic rhinitis, recurrent ear infections, asthma, tympanostomy tubes, previous adenotonsillectomy (T&A)), we included these elements in the 2nd model, which again revealed that a robust component of the risk for HS was attributable to neighborhood or PSI (RR: 2.34; 95% CI: 1.57-3.14; $p<0.001$). Similar findings emerged when familial history components (i.e., parental snoring and smoking) were introduced into the model, with neighborhood or PSI being associated with an increased risk for HS (RR: 3.18; 95% CI: 2.23-5.98; $p<0.0001$). We therefore proceeded to generate a 3rd logistic stepwise regression model that incorporated both clinical and familial history elements. This model revealed that either neighborhood location or PSI remained significantly associated with an increased risk for HS (RR: 1.87; 95% CI: 1.38-2.47; $p<0.001$). The regional differences of RR after adjusting for the all the potential confounders are shown in Figure 4 using the northern region (lowest pollution) as reference. Because many of the covariates can be directly affected by pollution, we proceeded to perform a stepwise regression analysis that initially examined the association between HS and age, sex, parental cigarette smoking, and all clinical history elements (RR: 2.43; 95% CI: 1.35-4.67; $p<0.001$). A second regression model was then calculated between PSI and parental smoking and clinical history characteristics (RR: 1.47; 95%:CI: 1.03-2.23; $p<0.01$), and used the residuals from this model, in the comprehensive model aiming to establish the adjusted association between PSI and HS, while adjusting for all other potential confounders while accounting for the interdependencies between air pollution and some of the key history elements. The findings from this model were remarkably similar to those described above as the 3rd stepwise regression model, i.e., that either neighborhood location or PSI remained significantly associated with an increased risk for HS (RR: 1.83; 95% CI: 1.31-2.28; $p<0.001$). Exclusion of the clinical history elements from this model, led as would be predicted to strengthening of the association between PSI and HS (RR: 2.83; 95% CI: 1.77-4.06; $p<0.00001$). Using a statistical approach that allows multiple risk factors to be taken into account (30), a total of 37.8 of HS could be attributed to air pollutants (17% to parental smoking, 20.8% to exposure to air pollution).

Discussion

This study shows that in addition to other previously established individual or familial risk factors, environmental air pollution is an important contributor to the prevalence of habitual snoring in school-aged children. Indeed, in this relatively homogeneous population of Iran, children residing within metropolitan neighborhoods in which a substantial air pollution burden is present exhibited a much greater and independent risk for the presence of HS than children living in neighborhoods where the environmental pollutants are not as high.

Tehran, the capital of Iran, is the one of the most populous and polluted cities in the Middle East. The city sprawls through a large surface area starting at the slopes of the Alborz mountains, and encompassing the large planes immediately at the foot of these mountains. The air quality in Tehran is largely defined by its geographic location, since the city is bound in the north by the high mountain range which stops the flow of the humid Caspian wind, and in the south by the central desert planes. As a large city with significant differences in elevation among various districts, it exhibits marked differences in air quality. The regional characteristics and differences in air quality enabled us to carry out the present study, and to identify air pollution as yet another major risk factor for the presence of HS in school-aged children. However, notwithstanding our current findings, it will be important to explore whether the same associations between air quality indicators and HS are confirmed in cities with less polluted air.

In past work, we have shown that an association between snoring and passive smoking is present in children, and that this association exhibits strong and dose-dependent effects of parental smoking (both parents smoking *versus* one smoking parent *versus* nonsmoking parents) on the frequency of snoring (4). These dose–response relationships have been since confirmed by others, and considering that the strength of the association appears to be stronger in younger children who spend more time at home or when maternal smoking is involved as opposed to paternal smoking, there is plausibility for a causal relationship linking exposure to cigarette smoking and HS (5, 18, 19, 31, 32). These observations would further support the concept that other environmental pollutants may also contribute to the epidemiological characteristics of HS in children. Indeed, Ekici and colleagues reported on the adverse effect of biomass pollution in rural areas as a major contributing factor to the presence of heightened prevalence of HS in rural environments (33). Recent work not only confirmed these assumptions, but further demonstrated that reduction in indoor biomass pollutants through targeted interventions consisting of cooking stove replacements was associated with major improvements in the frequency of snoring (24). Taken together, the existing evidence predicted that robust increases in the risk of HS would emerge in the current study among children living in the most polluted neighborhoods, and such hypothesis was indeed confirmed.

Upper airway inflammation is consistently present among children with either HS or OSA (34, 35), and inflammatory processes within the upper airway are likely to exacerbate upper airway collapsibility, as well as promote the proliferation of adenotonsillar tissues. In this context, it has become apparent that short-term exposures to traffic-related air pollutants may increase airway inflammation and/or oxidative stress in urban children (36-38), and therefore such processes would be unlikely restricted to the lower airways, and could in fact be even more prominent in the upper airways considering the relative concentrations of particles more likely to deposit in the upper segments of the airways (39, 40). In this setting, the unique characteristics of the city of Tehran allowed us to design this study based on the presence of a relatively homogeneous population, and the differential distribution of environmental pollutant risk factors that may contribute to the presence of snoring in children. The increases in HS prevalence associated with higher environmental pollution exposures either per se, or after adjustment for other known risk factors, would support the contention that such exposures will elicit chronic inflammatory processes in the upper airway that either cause or at least promote upper airway lymphadenoid tissue proliferation, and the emergence of HS. Considering the adverse health-related morbidities associated with HS, it would be intriguing to determine whether specific pollution control measures in future studies would not only lead to reductions in HS prevalence, but also to amelioration in some of these HS-associated morbidities, e.g., academic performance, prevalence of attention deficit hyperactivity behaviors, nocturnal enuresis or hypertension (7, 8, 10-13, 41). This possibility is all the more likely, when considering that at least 1/3 of the risk for HS is potentially attributable to avoidable risk factors (5).

Our study has replicated all of the previously identified risk factors for HS in other populations, including both clinical risk factors such as asthma, recurrent otitis, and need for tympanostomy tubes (42-44), as well as family-related risk factors such as parental snoring (4, 5, 21). The relative consistency and overall contribution of these factors across multiple ethnic and culturally diverse groups and environmental settings lends further credence to the existence of either causality or at least mediation relationships. However, we could not explore additional risk factors such as obesity or history of RSV infection using a questionnaire based approach. Similarly, we cannot exclude with certainty that despite efforts to validate the translated version of the questionnaire, certain terms may have difference meanings in different countries, and therefore can potentially lead to biased reporting.

Some methodological issues pertaining to the present study merit discussion. One of the major limitations of this study that is obviously shared by many of the other published community-based surveys is the lack of objective outcomes. Although we took precautions to translate and back-translate the questionnaire, it is important to note that the psychometric properties of the questionnaire were not specifically tested (45). Moreover, although we have recently shown that the receiver operator curve characteristics of the questionnaire used herein are relatively favorable for screening OSA in community children, we cannot infer what proportion of the children who fulfilled the criteria for HS actually have OSA (29). Furthermore, we did not have access to indoor pollution measurements or to specific school air quality measurements, such that the individual variations within each region could not be analyzed with the desirable detail that would enable further confirmation of the global findings described herein. Furthermore, we opted to exclude potential questions about socioeconomic status under the assumption that such quesiotns may markedly reduce participation in the survey. Notwithstanding, the regional differences in HS and their close tracking of the indicators of air quality provide a strong argument in support of a role for air pollutants in eliciting increased risk for HS in children.

In summary, in addition to previously identified risk factors, environmental air quality emerges as a significant and potentially modifiable contributor to the risk for developing HS during childhood, further emphasizing the multiplicity of factors that operate as determinants of upper airway lymph adenoid proliferation.

Role of each investigator: LKG provided conceptual initiative and design for the project, analyzed data, drafted components of the manuscript. MFGB composed the Farsi version of the questionnaire, collected data and contributed to data analyses. MS distributed and collected questionnaires and tabulated data. MHS collected data and assisted with data tabulation. DG provided the conceptual design of the project, analyzed data, drafted the manuscript, and is responsible the manuscript content. Drs. Gozal are the guarantors of this work, had full access to all the data, and take full responsibility for the integrity of data and the accuracy of data analysis. All authors have reviewed and approved the final version of the manuscript.

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Figure Legends

Figure 1. Representative heatmap of the city of Tehran based on air pollution reports for the years 2006-2007. The 5 regions from which schools were selected for the present survey are indicated by ellipses with green color and solid lines indicating very low pollution levels and black color and solid line indicating very high pollution levels. Blue triangles indicate school locations.

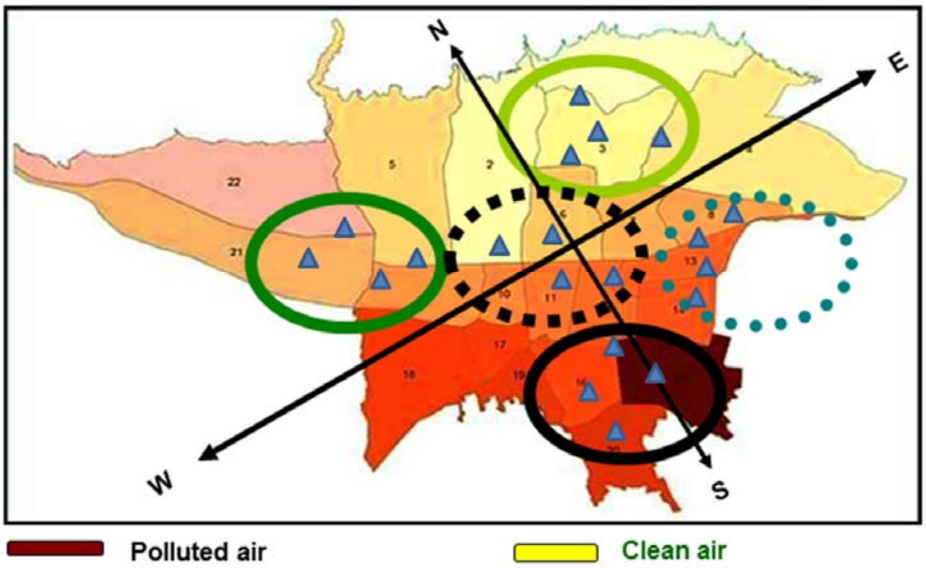

Figure 2. Percentage of responders to the “does your child snore” question in the questionnaire administered to 4,322 children according to age and based on “never”, rarely”, “sometimes”, or always or almost always (i.e., ≥3 nights/week or HS).

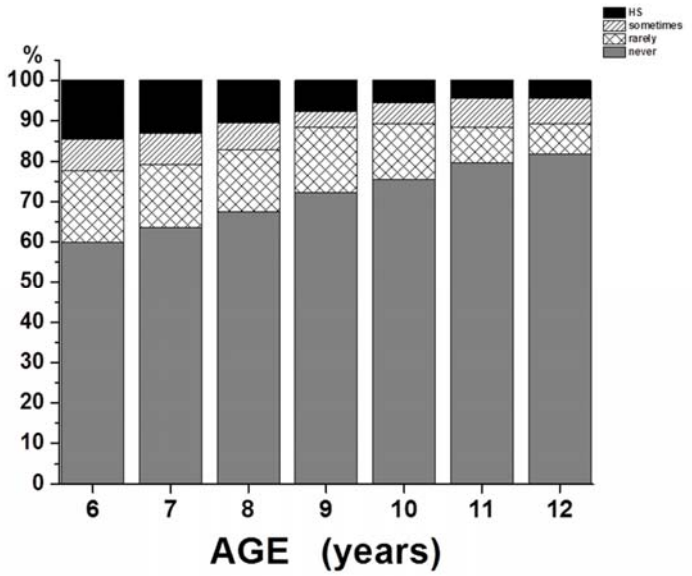

Figure 3. Perccentage of children fulfilling the criteria for habitual snoring according to age and gender.

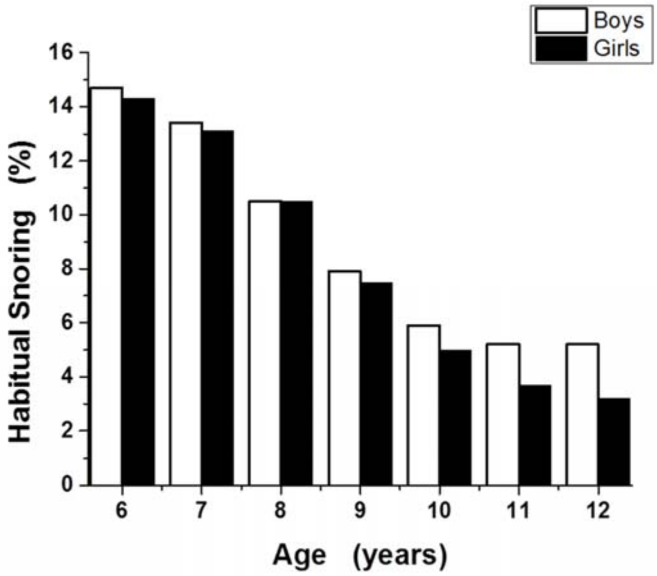

Figure 4: Regional relative risk for HS after adjusting for all potential confounders using the North region (N) as the reference region. The increases in adjusted RR closely track the differences in air quality recorded for those regions.

E – east; W – west; C – central ; S – south; Error bars indicate 95% CI

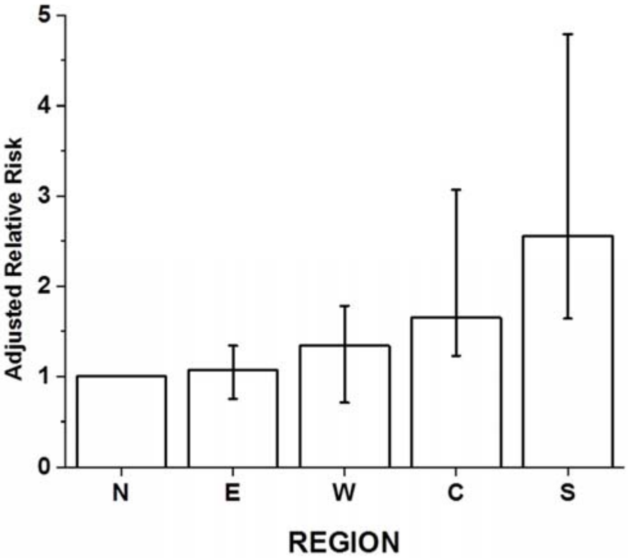

Table 1. Mean neighborhood air pollution levels and Pollutant Standards Index (PSI) during 2006-2007 in Tehran, Iran

City Region	Mean Air Pollution Levels				
	CO (ppm)	NO_2 (ppb)	O_3 (ppb)	PM_{10} (μg/m^3)	SO_2 (ppb)
N	5.7	29.3	78.7	42.9	21.3
S	3.6	94.8	112.4	106.8	46.6
E	1.3	39.7	88.8	66.8	13.7
W	1.6	45.6	76.7	63.0	10.3
C	5.5	76.0	104.6	90.4	39.4
PSI Air status 2007-2008	N	W	C	E	S
Clean	121	76	42	98	0
Healthy	511	456	113	491	56
Non-Healthy	68	168	525	111	537
Extremely Unhealthy	0	0	16	0	78
Dangerous	0	0	4	0	29

N, W, C, E, S represent North, West, Central, East, and South regions of the city of Tehran.

Table 2. Overall prevalence of habitual snoring, allergy, asthma, recurrent otitis, tympanostomy tube placement, and adenotonsillectomy (T&A) in 4322 school-aged children living in Tehran, Iran, and according to neighborhood location.

	All	**All**	**N**	**N**	**C**	**C**	**W**	**W**	**S**	**S**	**E**	**E**
	n	%	n	%	n	%	n	%	n	%	n	%
Distribution/area	4322	****	1011	23.39	701	16.21	736	17.02	800	18.5	1074	24.84
Habitual Snore	503	11.63	71	7.02	**85**	**12.12**	68	9.23	**196**	**24.50**	83	7.72
Allergy	775	18.1	203	20.38	165	23.6	141	19.31	100	12.62	166	15.58
Asthma	143	3.33	37	3.68	**35**	**5.0**	28	3.83	**55**	**6.85**	36	3.37
Recurrent Ear infections	185	4.3	58	5.79	31	4.42	22	3.0	29	3.62	45	4.22
Tympanostomy Tubes	40	0.93	10	1.0	**15**	**2.1**	4	0.54	**22**	**2.75**	12	1.12
T & A	299	6.95	59	5.86	**69**	**9.85**	64	8.76	**97**	**12.12**	65	6.08

N, W, C, E, S represent North, West, Central, East, and South regions of the city of Tehran.

Table 3. Unadjusted risk ratios for the presence of habitual snoring if previously identified risk factors were concurrently present among 4,322 children living in Tehran, Iran.

	Relative Risk	**95% C.I.**	**P value**
Allergic rhinitis	2.74	1.34-3.89	<0.01
Asthma	3.46	1.55-4.73	<0.001
Recurrent ear infections	2.37	1.12-3.44	<0.03
s/p tympanostomy tubes	2.87	1.67-3.78	<0.001
s/p T&A	4.78	2.72-7.66	<0.0001
Parental smoking	2.25	1.44-3.66	<0.001
Parental HS	2.43	1.39-3.87	<0.001

T&A - adenotonsillectomy