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Traffic-Related Air Pollution and Respiratory Tract Efficiency

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Abstract

High concentrations of air pollutants are characteristic of the vicinity of urban busy roads. Numerous studies have shown that these concentrations are significantly higher in comparison with areas located in a certain distance from roads and especially those in rural areas. Inhabitants living in the proximity of roads are, therefore, likely to be more exposed to adverse effects of air pollutants. On the basis of a study realized in 2008–2012 among nearly 5,000 residents of Warsaw and non-urbanized areas, we used generalized linear regression models (GRM) to identify factors that most significantly influence the variability of respiratory function variables. GRMs combine multiple classes of models and estimation methods such as simple, multiple, or factorial regression, ANOVA, ANCOVA, etc. Therefore, they allow receiving results based also on interactions between the independent variables. This paper presents the results of GRM for the forced expiratory volume in 1 s (FEV_1) distribution. They indicate that the variation of FEV_1 is associated with personal factors such as age, height, weight, BMI, or gender, as well as with factors related to the place of residence: traffic density, duration, and the floor of residence. The results clearly show that living in the proximity of busy roads in the city is linked with a significant decrease in FEV_1 values.

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Keywords
Air pollution • Bronchial obstruction • Generalized regression model • Health • Pulmonary function • Traffic congestion

1 Introduction

The implementation of air quality standards has contributed to a considerable reduction in emissions (mainly from industry and energy sector) and thus in improvement of air quality. Nevertheless, in many parts of Europe (especially in cities) air pollutants such as ozone, particulate matter, nitrogen dioxide, or polycyclic aromatic hydrocarbons still remain at high concentrations. To the greatest extent, the problem concerns the countries of Eastern Europe (Sauer et al. 2013), which was confirmed in a recent report on air quality in Europe (EEA 2013). Particularly, important contribution in this field have the emissions from the municipal sector as well as road traffic; the areas located in the immediate proximity of urban roads with high traffic density are characterized by elevated concentrations of various air pollutants such as CO, NO_2, PM, PAHs, and others (Majewski et al. 2013; Rogula-Kozlowska et al. 2013; Juda-Rezler et al. 2011; Brugge et al. 2007). There is a substantial number of studies from the last decade presenting the influence of vehicular traffic-originated air pollutants on health outcomes (e.g., Jedrychowski et al. 2005; Schikowski et al. 2005). Evidence of the health hazard of air pollutants arises, however, from much earlier work carried out even in the late 1970s (Pope et al. 2002).

At present, one of the most important air quality problems in Europe to be urgently addressed in terms of health is still high exposure of inhabitants to particulate matter pollution. It is estimated that in Europe 430,000 premature deaths could be attributed to exposure to ambient $PM_{2.5}$ (EEA 2013). Estimates made for the Polish conditions indicated that in the year 2000 almost 40,000 people died prematurely due to the exposure to $PM_{2.5}$ (Tainio et al. 2012). Both the size and chemical composition of particulates determine the health risk. PM smaller than 10 μm get through the throat and nose to lower parts of the respiratory tract, and especially those smaller than 3 μm are easily deposited in the pulmonary alveoli. Particles of even smaller diameters, through the lower parts of the respiratory system, may almost freely move to other organs (including the brain) around the circulation system (Nemmar et al. 2002). An increase in the concentration of fine particles in the air determines an increased incidence of hospital admissions due to respiratory diseases, most notable chronic obstructive pulmonary disease (COPD) (Dominici et al. 2006), a higher mortality rate due to cardiovascular diseases, and lung cancer (Pope et al. 2002). Infants seem particularly endangered (Anderson et al. 2011). Increasing concentrations of ultrafine particles (smaller than 0.1 μm), observed in the vicinity of roads during morning and evening traffic rush hours (Mishra et al. 2012), can even enhance the occurrence of hypertensive crisis (Franck et al. 2011). It has also been observed that exposure to urban traffic-related PM significantly increases cytotoxicity, oxidative stress, and pro-inflammatory response of lung epithelial cells and macrophages in comparison with PM from rural areas (Michael et al. 2013).

Results of a Swedish study indicate that living in a 100-m distance from a busy road (traffic intensity of over 10 cars per min), in comparison with a road of small traffic intensity, is connected with the incidence of the following diseases: bronchial asthma (OR = 1.40, 95 % CI, 1.04–1.89) and COPD (OR = 1.64, 95 % CI, 1.11–2.40) (Lindgren et al. 2009). Long-term exposure to air pollutants in urban environments, as a Norwegian study shows (Nafstad et al. 2004), may lead to increased mortality due to respiratory diseases. It may be inferred that the mortality risk factor due to respiratory diseases, other than cancer, amounts to 1.16 (95 % CI, 1.06–1.26), pulmonary cancer – 1.11 (95 % CI, 1.03–1.19), ischemic heart disease – 1.08 (95 % CI, 1.03–1.12), and cerebrovascular diseases – 1.04 (95 % CI, 0.94–1.15). Results of a cohort study conducted in Canada in a group of over 450,000 people has confirmed that long-term exposure to air pollution increases the incidence of ischemic heart disease – OR 1.29 (95 % CI, 1.18–1.41) among residents of buildings located 150 m away from a motorway or over 50 m away from a main road in comparison with other people (Gan et al. 2011). A Dutch study shows that even a short-term exposure to high concentrations of particles in the air is a detriment to pulmonary function, reduces airway resistance, and increases the possibility of inflammation (Zuurbier et al. 2010). A similar finding has been provided by an English study, where a short-term exposure to air pollution (NO_2, O_3, SO_2, or PM_{10}) contributed to aggravation of COPD symptoms (Peacock et al. 2011).

Lowering of the concentration of air pollutants in urban areas should be a priority in an effort to reduce the scale of health problems resulting from pollution. Legitimacy of such activity is demonstrated by the results of implementation of traffic restricted access zones in cities, such as in Milan, Italy (Invernizzi et al. 2011) or increasing the share of public transport and cycling in the modal split, such as in Barcelona, Spain (Rojas-Rueda et al. 2013).

2 Methods

2.1 Subjects

The study was approved by the Ethics Committee of the Military Institute of Medicine in Warsaw, Poland. Pulmonary function tests were conducted in 4,725 people living in the vicinity of 7 selected busy roads in the capital city of Warsaw, Poland and in rural areas isolated from a direct impact of air pollutant emissions, including traffic-related emissions (control group). Tests were performed from April to June and from September to October in the years 2008–2011. The selection of the study time took into account the avoidance of a potential influence of short-term effects of air pollutants from sources other than traffic (especially municipal and domestic sources) and holiday breaks, which could affect the representativeness of results. The subjects under treatment for COPD or asthma, and those who failed to cooperate with the experimenters were discarded from further analysis.

In Warsaw, 3,834 examinations were performed, including 1,608 women and 2,226 men aged 9–91 (mean 50.9 ± 19.7 years). The proportion of non-smokers was 50.5 % (1,938 people). The control (rural) group consisted of 891 individuals, including 471 women and 420 men aged 9–91 (mean 50.1 ± 19.1 years); 49.6 % of them (449 people) were non-smokers. The presentation of results was limited to the non-smoking people only, due to the general aim of this study, which was the assessment of the impact of traffic-related air pollution on spirometric variables.

2.2 Tests

The examination was conducted according to the following scheme:

- A testee was informed about the aim of the examination and that it has no harmful effect on the organism;
- Questionnaire-based interview, taking into consideration anthropometric features, characteristics of the place of residence, smoking habit burden, exposure to harmful factors in the workplace and the place of living, information about pulmonary diseases, presence of symptoms that might prove respiratory system disease, allergies, etc.;
- Pulmonary function tests carried out in a sitting position (EasyOne spirometers; ndd Medizintechnik AG, Zürich, Switzerland), preceded by a few-minute adaptation time. Several flow-volume curves were recorded until the repeatability criterion was achieved, in accordance with the American Thoracic

Society (Miller et al. 2005). The test included the following:

- FVC (forced vital capacity);
- FEV_1 (forced expiratory volume in 1 s);
- PEF (peak expiratory flow);
- MEF_{50} (maximum expiratory flow at 50 % of FVC);
- FEV_1/FVC ratio (pseudo-Tiffeneau factor).

According to the ATS guidelines (Miller et al. 2005), the study was carried out until at least 3 repeatable results of FVC and FEV_1 were obtained, i.e., differences between the measurements were less than 0.15 dm^3, total expiratory time was at least 6 s, and the time to reach the peak flow (PEF) was less than 300 ms. Values expressed in liters were converted into predicted values according to commonly used ERS/ECCS standards (Quanjer et al. 1993).

2.3 Statistical Analysis

Data are means ± SD, unless otherwise indicated. The Shapiro-Wilk test was used to test for the normality of data distributions. Differences were compared with a parametric (ANOVA) or non-parametric (Kruskal-Wallis) test, as required. Statistical significance was defined as $p < 0.05$. The assessment of factors determining the variability of spirometric variables was done with a generalized linear regression (GRM path). GRM is a kind of estimation path with a wide range of regression methods and models, prepared for the estimation of variables in all measurement scales and interactions between endogenous variables. Initial data analysis, based on the robust estimators and GRM results (Dffits ratio, Cook distance, and others), was made before GRM models and logistic regression identification. Among others, Kruskal-Wallis tests, ANOVA, cluster analysis, classical regression, and PCA were made to achieve partial aims and regulators before model identification. The GRM was used to assess the significance of external factors determining the variability of key spirometric variables. The analysis presented herein concerns the FEV_1 only. Statistical analyses were conducted using Statistica ver. 10 Software (StatSoft Inc., Tulsa, OK).

3 Results and Discussion

3.1 General Results

Among both the city and rural residents the mean predicted values for spirometric variables were generally in the normal range. In most cases, however, especially those in which bronchial patency was determined, significant differences between the groups have been observed. In city residents, FEV_1, MEF_{50}, and (FEV_1/FVC) were significantly lower than those in the rural inhabitants (*t*-test and Kruskal-Wallis test, $p < 0.001$). Significant differences were also noted for PEF. The FVC, on the other hand, did not differ significantly between the two groups. That implies that a higher exposure to air pollution does not much affect the FVC, although it should be noted that this parameter has a limited relevance from the clinical point of view. The results of spirometry are presented in Table 1.

Since there were differences in spirometric indices between the city and rural inhabitants, we calculated the percentage of people with airflow obstruction in each group. Figure 1 presents the results of this calculation as broken down by the levels of FEV_1/FVC and FEV_1

Table 1 Predicted values of spirometric indices among non-smoking inhabitants of Warsaw and the control group of rural residents

	Warsaw group		
	Percentage of predicted values (%)	Rural group	p
FEV_1	95.3 ± 19.3	100.3 ± 17.2	$p < 0.001$
FVC	107.5 ± 24.9	108.1 ± 18.9	$p = 0.64$
PEF	96.2 ± 24.2	100.5 ± 22.8	$p < 0.001$
MEF_{50}	75.0 ± 32.8	86.0 ± 31.3	$p < 0.001$
FEV_1/FVC	94.5 ± 14.4	98.6 ± 10.6	$p < 0.001$

Data are means ± SD

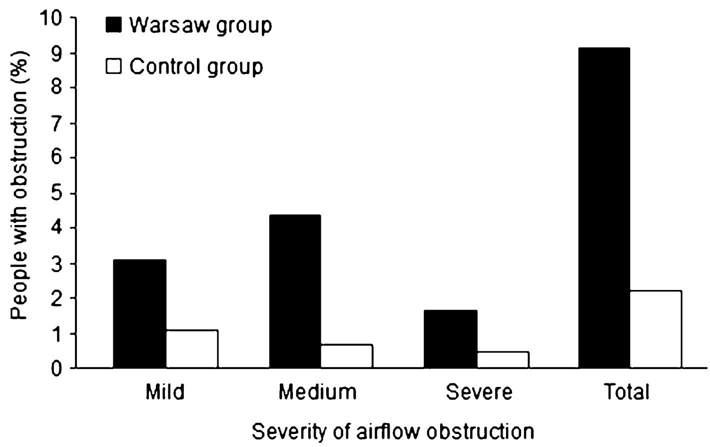

Fig. 1 Prevalence of airflow obstruction in urban and rural areas

corresponding to obstruction severity: mild – $FEV_1 \geq 80$ %, moderate – FEV_1 50–79 %, and severe – $FEV_1 < 50$ %.

The conducted observations show that among non-smokers:

- there is a significant decrease of values of the most important spirometric variables which reflect bronchial patency and possible adverse changes in the city residents compared with the control group of rural residents (Table 1);
- there are visible differences in the percentage of people with diagnosed obstruction between Warsaw and rural residents; relative risk of bronchial obstruction is 4.1-fold greater in city inhabitants (Fig. 1);
- Warsaw residents clearly have a moderate form of bronchial stricture, with FEV_1 lowered to 50–79 %. This is rather typical for smokers suffering from chronic obstructive pulmonary disease and not for people exposed to mainly environmental factors. The observation definitely needs further monitoring, also for economic reasons – with more advanced obstruction, treatment costs would be growing and quality of life would dramatically decrease, especially that the individuals examined were professional active.

3.2 Generalized Linear Regression Models (GRM) Results

In general, as indicated by the results of principal component analysis (PCA), spirometric indicators are close to each other in pairs, i.e., a specific parameter (e.g., MEF_{50}) and its equivalent in the percentage of predicted values (e.g., MEF_{50}%). This is illustrated in the principal component 2D projection (Fig. 2). It is assumed that a finding of similarities between pairs of spirometric indicators may be helpful in reducing the dimensions of multidimensional models and analysis, which will considerably simplify the calculations.

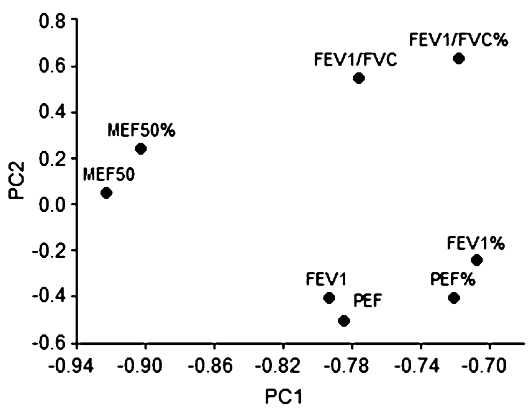

Fig. 2 Results of principal component (PC; without rotation) two-dimensional projection

However, regardless of the presumption of a connection between the variables in pairs, separate models for each variable were made. The model presented herein exemplifies FEV_1 and concerns the results of non-smoking patients only. The significant ($p < 0.05$) effects and their interactions are specified in Table 2. The results indicate that FEV_1 variability mostly depends on the demographic parameters, age or gender, duration of residence at a particular

Table 2 Generalized linear regression model (GRM) for FEV_1 distribution

	SS	Degrees of freedom	MS	F-value	P-value
Intercept	21.81	1	21.81	86.84	<0.0001
Age (years)	276.09	1	276.09	1,099.52	<0.0001
Height (cm)	69.13	1	69.13	275.29	<0.0001
Weight (kg)	4.10	1	4.10	16.34	0.0001
BMI (kg/m^2)	7.25	1	7.25	28.86	<0.0001
Duration of residence (years)	2.62	1	2.62	10.43	0.0013
Traffic (cars/day)	2.40	1	2.40	9.54	0.0020
Gender	57.96	1	57.96	230.84	<0.0001
Sports	2.97	1	2.97	11.82	0.0006
Gender*Passive smoking	2.10	1	2.01	8.35	0.0039
Sports*Place of residence	4.21	8	0.53	2.09	0.0333
Gender*Sports*Place of residence	6.34	8	0.79	3.16	0.0015

Traffic – daily average traffic density in the vicinity of residence, gender – (0-man, 1-woman), sports – physical activity (0-no, 1-yes), passive smoking exposure (0-no, 1-yes), place of residence – different locations of residence of city and rural area inhabitants (1–9), *interaction between variables
SS sum of squares, *MS* mean square

Table 3 SS-test results for the full model relative to SS for the residues

		Multiple R		Multiple R^2		Adjusted R^2
Dependent variable FEV_1		0.886		0.786		0.781
SS Model	df Model	MS Model	SS Rest	df Rest	MS Rest	F
2,102.78	25	84.11	574.52	2,288	0.25	334.97

place, traffic volume at the intersection of the nearest heavy traffic road, and on physical activity. Some interactions between variables were also significant. The SS-test for the presented complete model in relation to SS-test for the residues indicates that the model describes well the dependent variable (FEV_1), as it is evidenced by a relatively high value of the determination coefficient ($R^2 = 0.786$) (Table 3). The determination coefficient of 0.786 indicates that the 78.6 % of the variance of the dependent variable FEV_1 is explained by this model. Therefore, the remaining 21.4 % of the variation is explained by other unidentified factors. A good fit of the model is confirmed by the scatter plot of predicted *vs*. observed values (Fig. 3).

In addition to the standard evaluation of goodness of model fit to the empirical data, the residues were also evaluated. The calculated DFFITS values do not exceed ±1. It is, therefore, reasonable to conclude that there were no outliers observed among the remaining identified models, which would require further analysis.

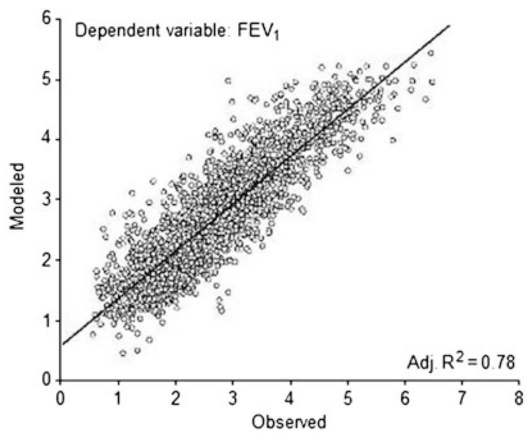

Fig. 3 FEV_1 observed *vs*. FEV_1 modeled (predicted)

4 Conclusions

The present study demonstrates that relative risk of bronchial obstruction is more than fourfold greater among non-smoking inhabitants of the vicinity of heavy traffic roads in a large city

(Warsaw), compared with that among inhabitants of rural areas, who are much less exposed to the influence of traffic-related air pollution. This conclusion stems from the analysis of key spirometric variables (FEV_1, FEV_1/FVC, and MEF_{50}) which are appreciably ($p < 0.001$) lower in city residents than in the rural group. This indicates an increased percentage of people who exhibit respiratory tract inflammatory reactions due to greater exposure to air pollution, which is in rapport with previous work in which multiple regression models also indicate decreasing values of FEV_1 and pseudo-Tiffeneau index among Warsaw residents (Badyda et al. 2013a, b). Lower values of these variables are linked with a shorter lifespan, particularly of city inhabitants and of those living on lower floors, which involves being in contact for prolonged periods of time stay with higher air pollution. A concentration of pollutants usually falls with increasing altitude (distance from emissions sources), with the exception of non-standard meteorological conditions.

The generalized regression model used in the present study for FEV_1 and the changeability of FEV_1 depend mostly on demographic factors, but also on such determinants as the place of residence, the vehicle traffic at the closest intersection of a busy street, and duration of residence. A decline of FEV_1 was increasing with increasing duration of residence in a particular place, which was partly related to the age of individuals, although the decline was stronger among city than in rural inhabitants.

To wrap it up, despite the complexity of the environmental factors influencing spirometric variables, the points to significant impact of road traffic and air pollutants on the respiratory health of inhabitants of big cities.

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Conflicts of Interest The authors declare no conflicts of interest in relation to this article.

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