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ORIGINAL ARTICLE / *ARTIGO ORIGINAL*

Evaluation of peak expiratory flow in adolescents and its association with inhalable particulate in a Brazilian medium-sized city

Avaliação do pico de fluxo expiratório em adolescentes e sua associação com material particulado em uma cidade brasileira de médio porte

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ABSTRACT: ***Introduction:*** High particulate matter (PM_{10}) concentrations are associated with increased incidence of respiratory symptoms and decreased lung function. This study evaluates the air pollution effects in children's and adolescents' lung function using peak expiratory flow (PEF) measurements over a given period, in an area exposed to industrial emissions. ***Methodology:*** This was a panel study. The effects of air pollution on respiratory symptoms and PEF were investigated in 117 children and adolescents from three public schools in areas of exposure to air pollution from a mining company in a Brazilian medium-sized city, from 2008 to 2009. The average daily PM_{10}, temperature and humidity were recorded by the monitoring network in the region. Association between daily records of PEF and PM_{10} was assessed in mixed-effect regression models, controlling for temperature, humidity, and body mass index. ***Results:*** About 60,000 PEF measurements were performed. Increases of 14μg/m^3 in PM_{10} were associated with decreased PEF in the morning (-1.04%, 95%CI -1.32; -0.77) and evening (-1.2%, 95%CI -1.49, -0.92). ***Discussion:*** We found a significant negative association between particulate matter and peak expiratory flow rate in this population, and these remained significant even after adjusted for temperature, humidity, body mass index, coughing, wheezing and coryza. ***Conclusion:*** Adverse effects were found and it suggests an association between increase in PM_{10} and reduced lung function.

Keywords: Air pollution. Particulate matter. Children. Adolescents. Longitudinal studies.

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RESUMO: ***Introdução:*** Altas concentrações de material particulado (MP_{10}) estão associadas com o aumento da incidência de sintomas respiratórios e a diminuição da função pulmonar. Este estudo avalia os efeitos da poluição do ar na função pulmonar de crianças e adolescentes, usando medições de pico de fluxo expiratório por determinado período, em área exposta a emissões industriais. ***Metodologia:*** Este é um estudo de painel. Os efeitos da poluição nos sintomas respiratórios e no pico de fluxo expiratório (PEF) foram investigados em 117 crianças e adolescentes, em três escolas públicas localizadas na área de dispersão da pluma dos poluentes emitidos por uma indústria de mineração em uma cidade brasileira de médio porte, em 2008 e 2009. Médias diárias de MP_{10}, temperatura e umidade foram coletadas pela rede de monitoramento na região. Associação entre registros diários de PEF e de MP_{10} foi avaliada utilizando modelos de regressão de efeito misto, controlando por temperatura, umidade e índice de massa corporal (IMC). ***Resultados:*** Cerca de 60 mil medidas de PEF foram realizadas. Aumentos de 14 $\mu g/m^3$ de MP_{10} foram associados com diminuições das medições do PEF da manhã (-1,04%, intervalo de confiança de 95% — IC95% -1,32; -0,77) e à noite (-1,2%, IC95% -1,49; -0,92). ***Discussão:*** Neste estudo encontramos associação negativa significativa entre exposição a MP_{10} e pico de fluxo expiratório. Essas associações permaneceram significativas mesmo após o ajuste para temperatura, umidade, IMC, sexo, tosse, chiado e coriza. ***Conclusão:*** Os efeitos adversos foram encontrados sugerindo associação entre o aumento de MP_{10} e a função pulmonar reduzida.

Palavras-chave: Poluição do ar. Material particulado. Criança. Adolescente. Estudos longitudinais.

INTRODUCTION

The increase in air pollution in urban areas has led to a sharp rise in children respiratory illnesses and has been considered an important cause of hospitalization[1-5]. Air pollution affects the population's health even when its concentration levels are below the air quality standards[2,6].

Adverse effects of air pollution include not only clinical outcomes such as hospitalization, decreased lung function and mortality, but also reduced quality of life, interfering with daily activities. Ecological time series studies on air pollution and human health effects have shown association between air pollution and daily hospital admissions, especially by respiratory diseases among children and the elderly[7-10].

Studies in different environmental conditions have indicated the acute impact of air pollution on human health, lung function and respiratory symptoms[1,4,5,7,9,10]. In particular, high concentrations of particulate matter (PM) are associated with higher incidence of respiratory symptoms and decrease in lung function[11-14].

Measurements of lung function by spirometry or peak expiratory flow (PEF), respiratory symptoms, acute exacerbations of asthma episodes in children and school absenteeism due to illnesses have often been made and also associated with various air pollutants. Panel studies have shown a decrease in lung function associated with high levels of air pollutants[2,12-17].

Effects of air pollution from industrial or urban areas stationary sources on the exposed population's health (morbidity and mortality) have not been studied thoroughly; opposite from studies that evaluated the effects of mobile sources[4,7,9,18,19].

The present study evaluates the effects of air pollution in children's and adolescents' lung function through peak expiratory flow (PEF) measurements over a given period, in an area exposed to industrial emissions from a mining company located in a Brazilian medium-sized city.

METHODS

This study was approved by the Ethics Committee for Research Project Analysis of the Clinics Hospital of the School of Medical Sciences at Universidade de São Paulo. All subjects selected were informed about the study and signed an informed consent form.

STUDY DESIGN

A prospective panel study was done using time series approach with daily indicators of peak expiratory flow measurements, respiratory symptoms, and daily concentrations of air pollutants and meteorological factors. The term "panel study" was defined as a prospective cohort study where individual levels of lung function or respiratory symptoms, as well as air pollutant records, were collected at least daily for not less than eight weeks 11.

SELECTION OF PARTICIPANTS

A panel of 121 subjects (8–16 years) was built by randomly selecting students enrolled in schools in the municipalities of Anchieta and Guarapari (study area). Data collection was focused on schools in the study area, assessing the population in different gradients of air pollution. The sample was proportional to the study area population encompassed in children and adolescent age groups (7–19 years), according to the classification used by the World Health Organization. The sample size calculation was based on the prevalence of respiratory diseases[20]. Pre-existing disease was not an exclusion criterion. Once included in the study, each participant had their data considered in statistical analysis until the end of the study, regardless of the period the children didn't participate of the study.

LOCATION AND DATA COLLECTION

Anchieta and Guarapari are municipalities in the State of Espírito Santo, Brazil, located at latitude 20°48'21" south and longitude 40°38'44" West, and latitude 20°39'28" south and longitude 40°30'39" West, respectively. The study area had a population of more than 120,000 residents in 2008, its economy is based on tourism and iron ore pelletizing, recognized as the main source of air pollution in the region[21]. Data was collected from May 2008 to May 2009.

AUTOMATIC ENVIRONMENTAL MONITORING

Daily levels of the atmospheric pollutant (PM_{10}) for each station were obtained from the private mining company (2008–2009), and they were supervised by a governmental agency. Minimum temperatures and mean humidity of the company were also obtained.

Daily measurements of PM_{10}, temperature and humidity were obtained from two automatic stations monitoring network located in the study area. The mean values of two stations were used.

Schools were from the public network and the population had similar socio-economic profiles in both municipalities.

PEAK EXPIRATORY FLOW RATE MONITORING

Currently, there are several tests to evaluate aspects related to lung function. To assess lung volumes, the tests commonly used are spirometry and peak expiratory flow (PEF). Lung function evaluation by PEF is simple, noninvasive, economical, fast and is used to assess strength and expiratory flow in L/min. It also serves to warn about the decline in lung function[22,23]. Thus, the chosen measure of effect was the peak flow test.

Over a one-year period, subjects were followed up, after the evaluators were trained for proper use and cleaning of the device, with PEF measures twice daily, one in the morning and one in the evening, with individual devices (Mini-Wright peak flow meter Clement Clarke, London, UK). A daily diary of respiratory symptoms and school absenteeism was filled out and monitored regularly by health workers involved in this study, who were trained to ascertain the correct examination and filling out of the diary.

During data collection, children and adolescents participated in monthly recreational meetings, where they were also supervised and instructed about the testing and given feedback on their participation in the study. Measurements were taken at the patient's homes, under their parents' supervision. Both (children and their parents) were trained by two respiratory physiotherapists who also supervised all participants along the study. Three trainees visited the participants at their households periodically.

PEF was monitored according to the parameters set by the I Brazilian Consensus on Spirometry[22]. The test was done by achieving the maximum inspiratory flow followed by the maximum forced expiratory flow, short and explosive through the measuring device. The expiratory effort lasted one to two seconds. The maneuver was repeated until three readings were within 20 L/min each. The highest of three readings was then recorded.

PEF predicted a value for each participant according to the Polgar equation[24] for both sexes. Based on this equation, predicted value for each participant was considered as per their height. Afterwards, the ratio between observed and predicted values was computed, named PEF percentage (PEF%).

For interpretation means, PEF% values were transformed in L/min, considering the overall average PEF measures.

STATISTICAL ANALYSIS

Descriptive analyses were conducted for all variables. Quantitative variables were presented as central tendencies and dispersion values[25]. The Kolmogorov-Smirnov and Levene tests were used to evaluate the normality and variance homogeneity, respectively.

To compare morning and evening PEF, the paired Student's t-test was applied.

Associations between PEF% records (morning and evening) and the air pollutant (PM_{10}) were assessed using linear mixed-effect models. As covariates, we included minimum daily temperature, daily average humidity, house environmental conditions (carpet, mold, humidity, pets), passive smoking, respiratory symptoms (cough, coryza), asthma, rhinitis, eczema, and body mass index. Bearing the nonlinear relationship between PEF% and weather variables in mind, natural spline functions were adopted for minimum daily temperature and daily average humidity. A random separated intercept value was fitted for each subject, the differences between all the subjects were controlled, and the reported estimates of association were effective from within-subject differences[26].

Because the effect of air pollution on peak flow may be distributed over time, the number of children with altered pulmonary function in a single day may stem from the exposure to pollutants not only during that day, but over the preceding days. As such, each peak flow measurement and PM_{10} was estimated on the concurrent and the previous days (each 1–7 preview days). The cumulative effects were assessed after the inclusion of two to seven-day movable averages of PM_{10}, and after the effects of an interquartile range of PM_{10} on peak flow measurements (morning and evening) were calculated.

SPLUS 5.0 and Statistical Package for the Social Sciences (SPSS), version 16.0 for Windows were used for data analysis. The level of significance was set at 5%.

RESULTS

Among the 121 participants selected, 86 (73.5%) remained in the study.

Table 1 shows the distribution of participants according to age, gender, household characteristics, presence of asthma, rhinitis, and eczema. Important to note that 35.9% of the sample was aged 11 and 12 years. Regarding gender, females were majority (52.1%). About house features, participants reported absence of carpet (79.5%), humidity (61.5%) and passive smoking (64.1%), but most of them had pets (62.4%). Participants with rhinitis were prevalent (51.3%), but without asthma (83.8%) or eczema (72.6%).

Table 2 shows mean and dispersion values of PM_{10} concentrations, along with atmospheric variables over the period of study. The average PM_{10} registered was 31.7 $\mu g/m^3$, and the interquartile range was 14.4 $\mu g/m^3$. The mean relative humidity in the period was 75.5%, and mean temperature was 20.3°C.

Mean Body Mass Index (BMI) was 19.7 Kg/m^2 (standard deviation = 3.3 Kg/m^2).

As shown in Table 3, mean morning PEF% was lower than mean evening PEF%. However, PEF% for both periods of the day were similar in terms of distribution and were

Table 1. Participants distribution according the age and sex. Espírito Santo, Brazil, 2008–2009.

	n (%)
Age (years)	
8–10	40 (34.2)
11–12	42 (35.9)
13–16	35 (29.9)
Gender	
Male	56 (47.9)
Female	61 (52.1)
Carpet	
No	93 (79.5)
Yes	24 (20.5)
Humidity	
No	72 (61.5)
Yes	45 (38.5)
Pet Animal	
No	44 (37.6)
Yes	73 (62.4)
Secondhand smoke	
No	75 (64.1)
Yes	42 (35.9)
Asthma	
No	98 (83.8)
Yes	19 (16.2)
Rhinitis	
No	57 (48.7)
Yes	60 (51.3)
Eczema	
No	85 (72.6)
Yes	32 (27.4)
Total	117 (100.0)

not statistically significant (Student's t-test, $p > 0.05$). Over the 12 months, 62,572 PEF measurements were performed in all subjects.

Interquartile-range increase in PM_{10} (14.4 $\mu g/m^3$) concentration was associated with decrease in both morning and evening PEF% (-1.04; 95%CI -1.32, -0.77 and -1.2; 95%CI -1.49, -0.92; respectively) at lag zero.

Figure 1 shows lag and moving average estimates and 95% confidence intervals (95%CI) of morning PEF% measurements. In the morning, the effects on peak flow were shown to be negatively significant at all lags and moving averages.

The effects on evening PEF% were also negatively significant at all lags, as shown in Figure 2. Moving averages were all significant.

Table 2. Descriptive analyzes of PM_{10} and weather variables. Espírito Santo, Brazil, 2008–2009.

	Relative humidity (%)	PM_{10} Average ($\mu g/m^3$)	Temperature average (°C)
Mean	75.5	31.7	20.3
Standard deviation	11.9	12.2	2.7
Minimum	18.44	9.2	13.14
Maximum	93.1	95.1	25.14
Percentiles			
5	64.0	15.7	15.5
25	72.4	23.3	18.6
50	77.2	29.7	20.5
75	81.7	37.7	22.6
95	87.6	54.7	24.4

Table 3. Descriptive analysis of peak flow measurements (PEF%).

	PEF morning	PEF evening
N	31 369	31 203
Mean (sd)	86.11 (12.83)	86.86 (12.69)
Median	86.65	87.17
Percentil 25–75	76.92–95.60	77.51-95.98
Minimum	56.46	57.39
Maximum	114.84	114.80

PEF%: peak expiratory flow percent of predicted values.

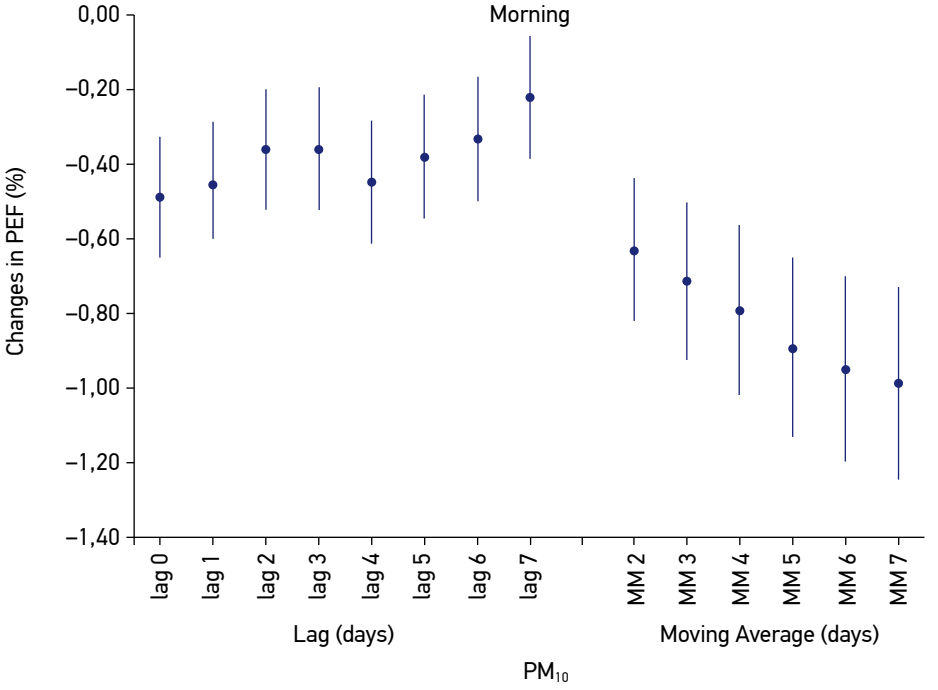

Figure 1. Lag and moving averages estimates and 95% confidence intervals of morning PEF%.

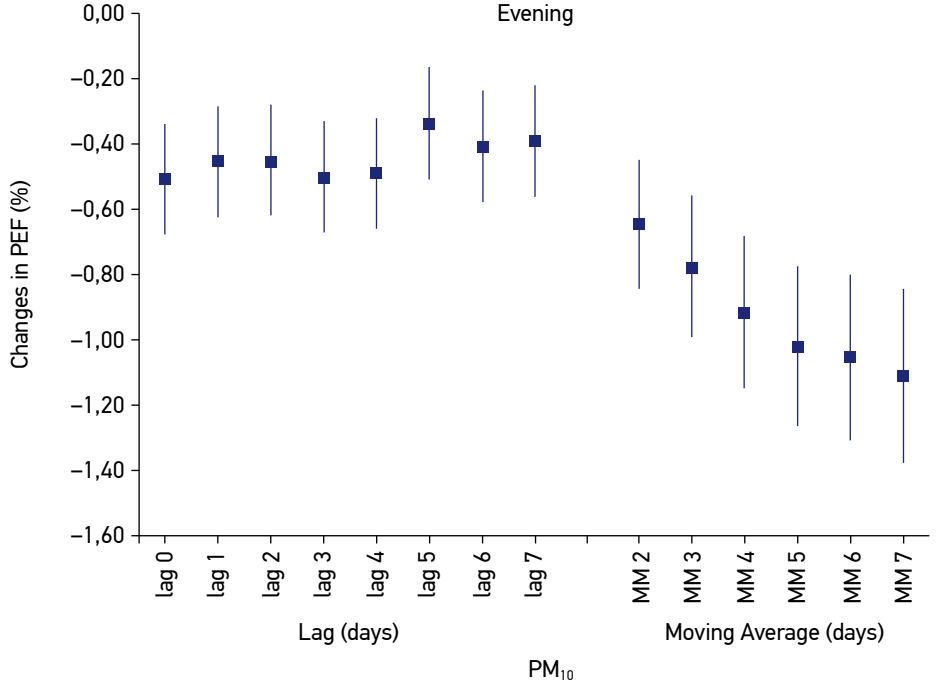

Figure 2. Lag and moving averages estimates and 95% confidence intervals in the evening PEF%.

Transforming PEF% results in PEF changes per L/min showed decreases of 3.35 L/min in the morning, and 3.89 L/min in the evening for the seven-day cumulative effect, according the mean PFE% found in the total period of the study.

DISCUSSION

This is a panel study conducted with children and adolescents living in a region near an iron ore pelletizing company aimed at evaluating their lung function. This study is part of a major investigation requested by the Secretary of State for the Environment based on the local population's questioning about the mining company expansion plans. The study object was whether the increase in air pollutant emissions could impact the area and the population's health. The strategy used to evaluate lung function was approved by the Government environmental agency and non-governmental environmental organizations and is aimed to identify early symptoms. Particulate matter was analyzed in terms of chemical specification.

Anchieta and Guarapari are medium-size cities, and, as opposed to Brazilian mega cities, mobile sources have not been the main source of air pollution emissions within their boundaries. The population recognizes the mentioned ore mining company as the responsible for environmental contamination.

The idea is to show that PM_{10} concentrations may contribute negatively to children and adolescents' health, reinforcing the importance of company expansion planning with discussions on possible health risks by air pollution increment.

In this study, we found a relevant negative association between particulate matter and peak expiratory flow measurements in this population, using daily concentrations of PM_{10} in linear mixed-effect models. Some of these associations remained significant after adjustment for temperature, humidity, body mass index, gender, coughing, wheezing and coryza. Other respiratory symptoms and exposure to household environmental factors did not show association in the models. Increased 24-hour mean concentration of PM_{10} was associated with decrease in both morning and evening PEF% (-1.04, 95%CI -1.32; -0.77 and -1.2, 95%CI -1.49; -0.92, respectively). These effects were strong in concentrations below the Brazilian air quality standards[27].

Hoek et al. (1998) analyzed data from five panel studies and reported a decrease in the population's mean PEF% for an increase of 10 $\mu g/m^3$ in the same day, PM_{10} concentration was 0.07%, averaged over all panels[14].

Decrease in lung function was also showed in a systematic review on studies about air pollution effects in children. The studies indicated more adverse effects of particulate air pollution for $PM_{2.5}$ than PM_{10}, according to a classic meta-analysis model, children's peak flow levels would decrease -0.012 L/min (95%CI -0.017; -0.008) and decrease -0.063 L/min (95%CI -0.091; -0.034) on average for a 10 $\mu g/m^3$ increase in PM_{10} and $PM_{2.5}$ levels, respectively[11].

Trenga et al. (2006) studied 57 adults with or without chronic obstructive lung disease (COPD) and 17 children aged 6 to 13 with physician-diagnosed asthma in Seattle in a 3-year panel study with PM measurements[16].

In Brazil, similar effects were obtained in a panel study from Rio de Janeiro, where air pollution was associated with reduction in students' lung function in the short term, increases of 10 μg/m³ in PM_{10} were related to decrease in peak flow, 0.34 L/min, varying between 0.32 L/min and 0.52 L/min, depending on the lag[2].

This association between peak flow decrease (morning and evening) and increased PM_{10} was found in asthmatic subjects in a panel study conducted in New Zealand with 93 male students (26 of them being asthmatic). Maximum levels of air pollution effects were associated with small but statistically significant effects on lung function in asthmatic but not in healthy students[17].

A previous panel study conducted with hospitalized children with severe asthma in Yotsukaido city, Japan, showed an association between increased mean concentration of $PM_{2.5}$ and decrease in both morning and evening PEF (-3.0 L/min; 95%CI -4.6; -1.4 and -4.4 L/min; 95%CI -7.1; -1.7, respectively). In addition, hourly concentrations of $PM_{2.5}$ related to PEF had significant association at some lags of $PM_{2.5}$ and PEF[12].

Our study also showed that atmospheric particulate matter is associated with worsening in lung function of children and adolescents (8–16 years old). In São Paulo, increases in respiratory disorders associated with PM_{10} were statistically significant[1,3].

Although the study area has acceptable levels of air pollutants, as per WHO standards[28], there is a source of steady air pollutant emissions: the mining company in the city, which may influence children's respiratory morbidity. In Rio de Janeiro, even when pollution remains below the recommended levels, there is an association between air pollution and the number of emergency pediatric consultations for respiratory problems[29].

A study carried out in a Brazilian small city in Minas Gerais showed the effect on respiratory morbidity among children using time series approach. An increase of 10 μg/m³ in PM_{10} was associated with 4% (95%CI 2.2 – 5.8) of children emergency room visits. PM_{10} generated by open pit mining is the main air pollution source in the city 18. The cities are similar: they have a very important fixed source of air pollution.

Studies confirm that the adverse effects to health caused by air pollutants can be seen even in medium-size cities, and children are highly susceptible to air pollution exposure[7,9,30].

One strength of this study was that each participant had PEF measured twice daily for one year, totaling more than 60,000 measurements of PEF. Other studies have showed similar results over shorter periods or with one daily measurement[2,12,17].

This is the first individual-based epidemiological study carried out in the State of Espírito Santo targeting the effects of air pollution exposure in children and adolescents living in medium-size cities.

This study is very important because it brings contributions to the debate about the impacts of future industrial expansion on health, relating it to increases in terms of morbidity and mortality. As Brazil has experienced an intense economic growth and the company in question basically exports iron ore, the expansion and construction of new pellet plants have been planned. Environmental organizations (public or not) should be supported by epidemiological studies for future decision-making.

The bias of PEF records made by participants could be pointed out as a possible limitation of our study, despite the supervision. The number of measurements (more than

60,000), however, may compensate this bias. The measures related to exposure in automatic air quality monitoring stations covered part of the studied area. In order to minimize bias, a campaign was set to measure $PM_{2.5}$, although some other limitations may be mentioned, such as small number of measurements over a short period. Nevertheless, this approach could help us establish an exposure criterion.

Record losses (26%) were above the estimated value for the study (20%), but a proportional loss occurred in each school.

CONCLUSION

Results show a strong association between PM_{10} emissions, in an area with important industrial source of air pollution, and decrease in PEF% of children and adolescents.

Industrial air pollution in a medium-size coastal city may adversely affect respiratory health of children and adolescents. In the scenario of economic growth seen in Brazil in the last decade, plants have been installed in different urban areas without having environmental and health impacts evaluated.

This study, as part of a demand from the Secretary of State for the Environment, assessed potential risks related to increased emission of air pollutants and the necessity to plan actions that minimize it and, consequently, its adverse health effects.

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