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Levels of Fine Particle Concentrations in Schools and Postexercise Pulmonary Function Disorders in Schoolchildren in Brazzaville

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Abstract

Context: Fine particles (PM2.5 and PM10) can accumulate in classrooms and in schoolyards located near urban roads. PM2.5 and PM10 can initiate, develop and exacerbate exercise-induced bronchospasm (EIB). This study aimed to assess the concentration levels of PM2.5 and PM10 in schools and to determine the rate of sensitivity to EIB among schoolchildren. **Methods:** A total of 128 students (67 girls and 61 boys) with an average age of 11 participated in this study. An ISAAC II questionnaire on respiratory symptoms was administered. PM2.5 and PM10 were measured. A 6-minute stress test was performed. Spirometry was performed. The ratio (I/O) of the concentrations of PM2.5 and PM10 recorded inside (I) the classrooms to those obtained outside (O) the classrooms was equal to 1 (I/O = 1). **Results:** The concentrations of PM2.5 and PM10 recorded inside the classrooms and those obtained outside the classrooms were higher than the values recommended by the WHO. 29 students out of 128 were diagnosed as sensitive to EIB [EIB (+)], *i.e.*, a rate of sensitivity to EIB of 22.66%. A drop in postexercise PEF of 17.396% was observed among EIB (+) students. **Conclusion:** Schoolchildren in schools located near highways are exposed to high levels of PM2.5 and PM10 concentrations. Exposure to PM2.5 and PM10 played an important role in the initiation and exacerbation of exercise-induced bronchospasm in schoolchildren from schools located near highways. Effective programs for improving air quality in schools must be put in place to reduce the effects of particulate pollution on the respiratory health of school children.

Keywords

Particulate Pollutants, Road Traffic, Exercise-Induced Bronchospasm, Schoolboy

1. Introduction

The ambient air in cities in developing countries is deteriorating yearly due to the increase in the number of second-hand vehicles. Vehicles emit pollutants into the ambient air such as carbon monoxide (CO), nitrogen oxides (NO_2, NO), sulfur dioxide (SO_2), volatile organic compounds (VOCs), fine (PM2.5 and PM10) and ultrafine particles and polycyclic aromatic hydrocarbons (PAHs) [1]. These air pollutants can accumulate on the playground and in the classrooms of schools located near roads with heavy traffic. A study of the relationships between outdoor and indoor pollution levels in classrooms in schools showed indoor/outdoor (I/O) ratios that ranged from 0 to 0.45 for ozone (O_3) between 0.5 and 1 for NO and between 0.88 and 1 for NO_2 [2]. These authors also observed ratios of indoor pollution levels in classrooms to outdoor pollution levels (I/O) close to 1, showing the equality between indoor pollution and outdoor pollution of classrooms.

Furthermore, the results of a study conducted by Annesi-Maesano *et al.* [3] revealed that in 108 primary schools, nearly 30% of pupils, *i.e.*, 3 out of 10 children, would be exposed to levels of pollutants above the standards authorized by the WHO. The same study showed that exposure to high concentrations of fine particles and VOCs was associated with an increased prevalence of asthma and rhinitis among school children. Additionally, the work of Zhang *et al.* [4] showed that a 10 μg/m^3 increase in PM2.5 inside classrooms was associated with a −2.09 L/min change in evening PEF (95% CI: −3.73 L/min to −0.51 L/min) after adjusting for season, size and sex, temperature and relative humidity. The results of a study conducted among children aged 12 to 14 with or without asthma and exposed to air pollutants showed significant effects regarding NO_2 and CO for bronchoconstriction [5]. Numerous studies have revealed an association between exposure to fine particles and the reduction in lung function parameters [6] [7] [8]. A recent study found a decrease in FVC, FEV1 and PEF for each 10 μg/m^3 increase in the one-day average PM2.5 concentration among school children [9]. Bergstra *et al.* [10] showed that exposure to PM2.5 and NO_X was linked to significantly lower lung function in schoolchildren.

In addition, living close to (less than 150 m) a main road with heavy traffic is responsible for 15% to 30% of new cases of asthma among children [11]. The results of the study by Gauderman *et al.* [12] demonstrated impaired respiratory function in children aged 10 to 18 living less than 500 m from a highway. Exposure to pollution from automobiles leads to risks of respiratory diseases and can induce postexercise pulmonary function disorders in schoolchildren [5] [13]. In addition, the worldwide average prevalence of exercise-induced bronchospasm (EIB) in the general population of children and adolescents is 9%, with a higher rate of 12% in the Asia-Pacific region and America [14].

In addition, road traffic is becoming increasingly dense in the cities of sub-Saharan countries in general and in the city of Brazzaville in particular. This is due to the increase in the number of used vehicles, mainly from Europe and Asia. These old vehicles pollute the ambient air of the city enormously. The objectives of this study were to assess the ratios of indoor pollution to outdoor pollution (I/O) of classrooms for fine particles in schools located near road traffic and to determine the prevalence of EIB among schoolchildren exposed to fine particles.

2. Materials and Methods

2.1. Study Participants

This study recruited 128 school children of both sexes averaging 11 years of age at the end of the second term of the 2021-2022 school year precisely in March 2022. The students attended the "Angola Libre" primary school located at the crossroads of Avenue of the Djoué (formerly Avenue of the OUA) and Avenue of the "Château d'eau" in arrondissement 2 Bacongo, Brazzaville. The subjects were in the first year of middle school (MS1) and second year of middle school (MS2) and had an attendance duration of 5 years or more in the school. Lessons are given Monday to Saturday from 7 a.m. to 12 p.m. for the morning wave and Monday to Friday from 12p.m. to 5p.m. for the afternoon wave.

2.2. Sample Size Calculation

Before data collection, we performed an a priori power analysis to determine the maximum sample size needed to detect the expected effect. We used the G*Power program (version 3.1.9.2) [15]. With a power of 0.90, setting the type I error at $p < 0.05$, assuming an effect size of 0.6 with a ratio of 3 between the two groups, the power analysis for the independent student test revealed a sample size of 130 subjects. As two subjects were excluded, the size of the sample was reduced to 128 subjects including 99 in EIB (−), and 29 subjects in EIB (+).

2.3. Procedures

Measurements of fine particles (PM2.5 and PM10) were carried out continuously from the beginning to the end of classes (7 a.m. to 5 p.m.) for 5 days and the concentrations of PM2.5 and PM10 were measured every 10 minutes in the MS1 and MS2 classrooms and in the schoolyard. Spirometry tests were performed before and 5 minutes after the stress test. Demonstration sessions for the spirometry test were carried out, and each subject had three spirometry test trials to perform in a room equipped within the school. The stress test was carried out in the schoolyard. These tests took place in the morning precisely from 8 a.m. to 12 p.m. Measurements of ambient temperature and relative humidity were taken at the start and end of the stress test.

2.4. Measurements of Particulate Pollutants

Measurements of fine particles (PM2.5 and PM10) were carried out continuously from the start to the end of classes precisely from 7 a.m. to 5 p.m. and the concentrations of PM2.5 and PM10 were measured every 10 minutes at inside the MS1 and MS2 classrooms for 5 days and outside the classrooms, especially in the schoolyard, for 5 days using a Temtop Airing-1000 particle detector (Elitech Technology, Inc. San Jose, CA 95131, United States. support@elitechus.com).

2.5. Pulmonary Function Test

After the addition of the height, body mass, sex and date of birth information of the subjects to the central unit of spirobank G through the WinspiroPRO software (version 5.7.2) installed in the microcomputer and a phase explanation and demonstration of the progress of the spirometry test and the familiarization tests with the spirometer, the subjects carried out three spirometry tests each. Disposable mouthpieces were used to observe medical hygiene.

2.6. Bronchial Provocation Test

A bronchial provocation test was performed by the participants in this study. This test was a 6-minute endurance race carried out according to the recommendations of the European Respiratory Society (ERS) [16] and the American Thoracic Society (ATS) [17]. Ambient temperature and relative humidity were measured at the start and end of the stress test.

2.7. Diagnostic Criteria for Exercise-Induced Bronchospasm

Based on the work of Ouattara *et al.* [18] and Thole *et al.* [19], a decrease in postexercise peak expiratory flow (PEF) greater than or equal to 15% compared to pre-exercise PEF was retained as a criterion for diagnosing exercise-induced bronchospasm (EIB) in subjects participating in this study. This criterion allowed us to identify the subjects who were positive or sensitive to EIB to form EIB (+) group and the subjects who were negative or not sensitive to EIB to form the EIB (−) group.

2.8. Sensitivity to EIB

The PEF values obtained before and after the exercise test made it possible to calculate the maximum drop in the percentage of PEF (% DEP) by using the calculation of the percentage reduction in the PEF post exercise compared to the pre-exercise value by the formula [20] as follows: % PEF = (post effort PEF – pre effort PEF) × 100/Pre effort PEF

2.9. Variables Studied

PEF was the dependent variable, and the stress test scores, PM2.5 and PM10 were the independent variables. Ambient temperature and relative humidity were the confounding variables.

2.10. Statistical Analysis

The Kolmogorov-Smirnov test and the Snedecor F test were used to verify the normality and homogeneity of the variances of variables. The non-parametric Wilcoxon test was used to compare the concentrations of PM2.5 and PM10 recorded inside the classrooms and those obtained outside the classrooms. The Student t test for unpaired series was used to compare the anthropometric and lung function variables between the EIB (−) group and EIB (+) group. The Student t test for paired series was also used to compare the average values of ambient temperature and relative humidity recorded during the stress test in EIB (−) and EIB (+). Statistical analysis of the data was performed using SPSS version 21.0 software and the significance of the differences was set at $p < 0.05$.

2.11. Ethical Considerations

This study has been approved by the Scientific Council of the Higher Institute of Physical and Sports Education of MARIEN NGOUABI University in the Republic of the Congo in accordance with the 1975 Helsinki declarations relating to ethics. The informed consent was read and approved by the parents of the students who participated in the study.

3. Results

To determine the air quality in schools located near highways, the concentrations of PM2.5 and PM10 were measured inside and outside the classrooms (**Table 1**). The average concentrations of PM2.5 and PM10 recorded inside (I) of the classrooms and those obtained outside (O) of the classrooms did not show any significant difference, and the I/O ratio was equal to 1 (I/O = 1) (**Table 1**).

Table 1. Comparison between average concentrations of PM2.5 and PM10 recorded inside (I) classrooms and those obtained outside (O) classrooms and with the values recommended by the WHO.

Parameters	Concentrations recorded inside the classrooms (I)	Concentrations recorded outside the classrooms (O)	Test	Values recommended by WHO	Ratio
	Mean ± SD	Mean ± SD	p value	24 hours	I/O
PM2.5 (μg/m^3)	60.104 ± 54.918 [15.90 - 513.80]	50.595 ± 33.667 [12.40 - 222.50]	0.125	15	1.188
PM10 (μg/m^3)	84.834 ± 77.572 [22.30 - 719.60]	75.335 ± 49.796 [17.30 - 311.80]	0.638	45	1.126

PM2.5: fine particle with a diameter of less than 2.5 μm; PM10: fine particle with a diameter of less than 10 μm; (I): Particulate matter concentrations recorded inside the classrooms; (O): Particulate matter concentrations obtained outside the classrooms; (I/E): Ratio between particulate matter Concentrations recorded inside the classrooms and those obtained outside the classrooms.

The diagnosis of EIB was based on a decrease in postexercise PEF greater than or equal to 15% compared to pre-exercise PEF. Twenty-nine students of both sexes out of 128 presented a decrease in postexercise PEF greater than or equal to 15%, *i.e.*, a rate of sensitivity to EIB of 22.66% (**Table 2**).

Comparisons of the average PEF values recorded before and after exercise were made between the subjects of the EIB (−) group and the EIB (+) group (**Table 3**). Before the exercise, no significant difference was observed between the mean value of the PEF recorded among the subjects of the EIB (−) group and that obtained among the subjects of the EIB (+) group. On the other hand, a significant difference was observed between the postexercise PEF of the EIB (−) group and that of the EIB (+) group (**Table 3**).

Table 2. Diagnosis of exercise-induced bronchospasm (EIB) based on a decrease postexercise peak expiratory flow of at least 15% compared to pre-exercise peak expiratory flow (PEF).

Subjects	PEF before effort (L/s)	PEF after effort (L/s)	Variation of PEF post effort (% delta)	Diagnosis Result	Subjects	PEF before effort (L/s)	PEF after effort (L/s)	Variation of PEF post effort (% delta)	Diagnosis Result
1	4.41	3.94	−10.66	Negative	**65**	4.72	5.04	6.78	Negative
2	4.26	4.37	2.58	Negative	**66**	4.22	4.32	2.37	Negative
3	4.57	4.79	4.81	Negative	**67**	4.55	4.84	6.37	Negative
4	6.09	7.19	18.06	Negative	**68**	4.29	5.43	26.57	Negative
5	3.92	3.53	−9.95	Negative	**69**	5.31	5.13	−3.39	Negative
6	3.65	3.43	−6.03	Negative	**70**	4.36	3.93	−9.86	Negative
7	4.86	4.46	−8.23	Negative	**71**	4.67	4.07	−12.85	Negative
8	4.63	4.79	3.46	Negative	**72**	5.13	5.04	−1.75	Negative
9	3.93	3.93	0.00	Negative	**73**	5.37	5.61	4.47	Negative
10	3.49	3.22	−7.74	Negative	**74**	4.46	4.55	2.02	Negative
11	4.34	3.9	−10.14	Negative	**75**	3.76	4.24	12.77	Negative
12	3.51	3.49	−0.57	Negative	**76**	4.15	3.81	−8.19	Negative
13	6.49	6.12	−5.70	Negative	**77**	5.65	5.4	−4.42	Negative
14	5.58	5.09	−8.78	Negative	**78**	4.57	3.98	−12.91	Negative
15	4.21	4.18	−0.71	Negative	**79**	4.99	5.01	0.40	Negative
16	5.26	4.88	−7.22	Negative	**80**	4.35	4.39	0.92	Negative
17	6	6.16	2.67	Negative	**81**	3.76	3.35	−10.90	Negative
18	4.97	4.37	−12.07	Negative	**82**	5.49	5.34	−2.73	Negative
19	4.55	5.06	11.21	Negative	**83**	3.74	3.37	−9.89	Negative
20	5.1	4.57	−10.39	Negative	**84**	3.71	3.44	−7.28	Negative
21	4.33	4.45	2.77	Negative	**85**	4.27	5	17.10	Negative
22	4.76	4.78	0.42	Negative	**86**	4.16	5.45	31.01	Negative
23	4.94	4.48	−9.31	Negative	**87**	6.12	6.53	6.70	Negative
24	4.23	4.07	−3.78	Negative	**88**	4.99	5.19	4.01	Negative
25	4.66	4.21	−9.66	Negative	**89**	6.38	6.24	−2.19	Negative
26	6.14	5.78	−5.86	Negative	**90**	3.68	3.27	−11.14	Negative

Continued

27	5.01	4.89	−2.40	Negative	**91**	4.55	4.61	1.32	Negative
28	3.26	2.9	−11.04	Negative	**92**	4.78	4.44	−7.11	Negative
29	4.48	3.99	−10.94	Negative	**93**	3.84	4.75	23.70	Negative
30	4.19	3.94	−5.97	Negative	**94**	4.38	4.3	−1.83	Negative
31	4.52	4.26	−5.75	Negative	**95**	3.68	3.14	−14.67	Negative
32	4.81	5.9	22.66	Negative	**96**	5.82	6.18	6.19	Negative
33	5.24	4.97	−5.15	Negative	**97**	3.73	4.45	19.30	Negative
34	5.72	5.55	−2.97	Negative	**98**	5.41	5.32	−1.66	Negative
35	4.13	3.77	−8.72	Negative	**99**	6.29	5.61	−10.81	Negative
36	5.95	5.8	−2.52	Negative	**100**	2.96	2.38	−19.59	Positive
37	4.68	5.58	19.23	Negative	**101**	4.24	2.8	−33.96	Positive
38	5.19	5.14	−0.96	Negative	**102**	5.25	2.84	−45.90	Positive
39	6.82	6.12	−10.26	Negative	**103**	6.1	5.08	−16.72	Positive
40	4.43	4.44	0.23	Negative	**104**	4.34	3.06	−29.49	Positive
41	5.07	5.04	−0.59	Negative	**105**	4.45	3.68	−17.30	Positive
42	4.55	4.52	−0.66	Negative	**106**	5.37	3.4	−36.69	Positive
43	4.02	4.28	6.47	Negative	**107**	4.88	3.93	−19.47	Positive
44	3.94	4.28	8.63	Negative	**108**	4.66	3.11	−33.26	Positive
45	3.18	3.38	6.29	Negative	**109**	4.78	3.86	−19.25	Positive
46	4.31	4.83	12.06	Negative	**110**	4.36	3.63	−16.74	Positive
47	3.67	3.52	−4.09	Negative	**111**	4.51	3.29	−27.05	Positive
48	4.94	4.97	0.61	Negative	**112**	5.55	4.59	−17.30	Positive
49	4.38	4.37	−0.23	Negative	**113**	5.48	4.16	−24.09	Positive
50	5.37	5.16	−3.91	Negative	**114**	6.4	4.81	−24.84	Positive
51	3.53	3.25	−7.93	Negative	**115**	4.43	3.06	−30.93	Positive
52	3.49	3.94	12.89	Negative	**116**	3.78	2.73	−27.78	Positive
53	4.18	3.66	−12.44	Negative	**117**	5.36	4.44	−17.16	Positive
54	5.27	5.12	−2.85	Negative	**118**	5.31	4	−24.67	Positive
55	6.63	6.66	0.45	Negative	**119**	6.05	4.76	−21.32	Positive
56	5.74	5.86	2.09	Negative	**120**	5.23	4.39	−16.06	Positive
57	4.36	3.87	−11.24	Negative	**121**	5.44	4.17	−23.35	Positive
58	4.44	4.42	−0.45	Negative	**122**	4.57	3.78	−17.29	Positive
59	3.42	3.3	−3.51	Negative	**123**	4.77	3.96	−16.98	Positive
60	5.59	5.52	−1.25	Negative	**124**	4.98	4.11	−17.47	Positive
61	4.46	3.9	−12.56	Negative	**125**	5.01	3.93	−21.56	Positive
62	5.19	5.36	3.28	Negative	**126**	5.22	4.18	−19.92	Positive
63	5.8	5.99	3.28	Negative	**127**	5.56	4.68	−15.83	Positive
64	5.75	5.09	−11.48	Negative	**128**	5.76	4.88	−15.28	Positive

To identify the variables on which the sensitive and nonsensitive EIB groups may differ and to take them into account in subsequent analyses, we compared the groups' anthropometric characteristics, in particular age, height, body mass (BM) and body mass index (BMI), and presented them as means and standard deviations (Table 3). The two groups, sensitive (EIB (+)) and nonsensitive (EIB (−)) to EIB groups were significantly identical with regard to age, height, body mass and body mass index (Table 3).

Table 3. Anthropometric and respiratory characteristics observed in the total group and comparison between BIE (−) and BIE (+).

Parameters	Total Group (n = 128)	EIB (−) (n = 99)	EIB (+) (n = 29)	Test	Delta
	Mean ± SD	Mean ± SD	Mean ± SD	p value	%
Age (year)	11.125 ± 1.236	11.172 ± 1.262	10.966 ± 1.149	0.410	−1.844
Height (cm)	145.805 ± 8.183	146.040 ± 8.247	145.000 ± 8.049	0.546	−0.712
Weight (kg)	35.258 ± 7.126	35.505 ± 7.257	34.414 ± 6.711	0.453	−3.073
BMI (kg/m²)	16.451 ± 2.192	16.499 ± 2.144	16.287 ± 2.379	0.670	−1.285
PEF_Bef (L/s)	4.771 ± 0.810	4.706 ± 0.826	4.993 ± 0.726	0.076	6.099
PEF_Aft (L/s)	4.478 ± 0.921	4.662 ± 0.894	3.851 ± 0.721***	0.000	−17.396

BMI: Body Mass Index; PEF_ Bef: Peak expiratory flow before exercise; DEP_ Aft: Peak expiratory flow after exercise; EIB (−): subjects sensitive to EIB; EIB (+): subjects not sensitive to EIB; Test: comparison of mean values between BIE (−) and BIE (+); Delta %: percentage variation of the values of the BIE (−) group compared to the values of the BIE (+) group; *: $p < 0.05$; SD: Standard Deviation.

4. Discussion

The concentrations of PM2.5 and PM10 recorded inside and outside the classrooms were higher than those recommended by the WHO (**Table 1**). These high concentrations of PM2.5 and PM10 observed inside and outside the classrooms can be explained by the increase in the number of second-hand vehicles in the city of Brazzaville. Indeed, in 2009, Brazzaville had approximately 11,490 vehicles, of which 8935 were used vehicles according to the National Center for Statistics and Economic Studies (CNSEE) [21]. These obsolete vehicles pollute the urban ambient air enormously.

In addition, air pollution related to road traffic has been implicated as a factor in the dysfunction of the respiratory tract. Studies have shown decreases in pulmonary volumes and flows and alterations in respiratory function associated with exposure to fine and ultrafine particles related to road traffic [6] [22] [23]. Wu *et al.* [24] found associations between fine particles, high ambient temperature and decline in lung function. One study showed that exposure to ultrafine particles among cyclists was associated with inflammation of the airways, and a decrease in lung function 6 h after exposure [25].

The present study showed a prevalence of exercise-induced bronchospasm (EIB) of 22.66% and a mean decrease in postexercise PEF of 17.396% among subjects in the EIB (+) group (**Table 2** and **Table 3**). The EIB sensitivity rate of 22.66% observed among school-children exposed to suspended particulate matter was very high. The ratio (I/O) of the average concentrations of PM2.5 and PM10 recorded inside (I) of the classrooms and those obtained outside (O) of the classrooms was equal to 1 (**Table 1**), showing an equality between indoor PM pollution and outdoor PM pollution. The very high prevalence rate of EIB highlighted in this study could be explained by long-term exposure to high concentrations of PM2.5 and PM10 mainly from road traffic. The work of Mohammadreza Modaesi *et al.* [26] showed that exposure to high concentrations of PM10 is associated with a high prevalence of EIB. In addition, one study observed a global average prevalence of EIB of 9% in the general population of children and adolescents aged 5 to 18 years [14]. This same study revealed a high rate of EIB of 12% among children and adolescents in the Asia-Pacific region and America [14]. Benarab-Boucherit *et al.* [27] observed an EIB sensitivity rate of 13% among schoolchildren in Annaba, Algeria. These authors [27] concluded that the polluted environment of the city could facilitate these characteristics of a rather high bronchial hyperresponsiveness.

The results of a cross-sectional study conducted by Hwang and Lee [5] among children aged 12 to 14 with or without asthma and exposed to atmospheric pollutants showed significant effects concerning NO_2 and CO for bronchoconstriction. In addition, numerous studies have revealed an association between exposure to fine particles (PM) and a reduction in lung function parameters [6] [7] [8]. In addition, a recent study found a decrease in FVC, FEV1 and PEF for each 10 μg/m^3 increase in PM2.5 concentration over one day in school children [9]. Another modeled cross-sectional study showed that exposure to PM2.5 and NO_X was linked to significantly lower lung function among school-children [10]. Moreover, the results of one study showed that a 10 μg/m^3 increase in PM2.5 inside classrooms was associated with a −2.09 L/min change in PEF of the evening (95% CI: −3.73 L/min to −0.51 L/min) among children who attended school [4].

In this study, long-term exposure to PM2.5 and PM10 played an important role in the initiation, development and exacerbation of EIB in schoolchildren. In addition, a variety of methods are used to diagnose EIB, including diagnosis based on eucapnic voluntary hyperpnea, methacholine, inhaled mannitol, hypertonic saline aerosol, histamine and field conditions from a physical exercise and laboratory conditions using incremental testing. The studies by de Aguiar *et al.* [14] and Benarab-Boucherit *et al.* [27] used the field test (exercise test) to diagnose EIB. Additionally, a variety of EIB diagnostic criteria have been used. Several studies consider a test to be positive for EIB when the decrease in postexercise FEV1 is greater than or equal to 10% compared to pre-exercise FEV1 [14] [20]. Other studies consider a test positive for EIB when the decrease in post-exercise PEF is greater than or equal to 15% compared to pre-exercise PEF [27] [28]. The present study used the field test (exercise test) to diagnose EIB, and the test was considered positive for EIB when the decrease in PEF after exercise was greater than or equal to 15% compared to the PEF before exercise.

In this study, the average concentrations of PM2.5 and PM10 recorded inside (I) of the classrooms and those obtained outside (O) of the classrooms did not show any significant difference, and the I/O ratio was equal to 1 (I/O = 1) (**Table 1**). These results showed significant equality between indoor air pollution and outdoor air pollution with respect to PM2.5 and PM10. The use of face masks, vehicle cabin filters or indoor air purifiers, may play an important role given emerging evidence suggesting that they may be effective in reducing the cardiorespiratory effects of air pollution to some extent [29]-[35].

In addition, the anthropometric characteristics of the subjects that were likely to influence the pulmonary function variables were compared between the EIB (+) and EIB (−) groups. These comparisons did not show any significant difference (**Table 3**). These results showed the equivalence of the two study groups. Note that during the stress test, the ambient temperature and relative humidity fluctuated between 30.57˚C and 30.61˚C, and between 54.47% and 54.51% on average respectively.

It should be noted that the majority of second-hand vehicles circulating in the city of Brazzaville considerably increase the levels of PM2.5 and PM10 concentrations in the courtyards and classrooms of schools located near roads with heavy traffic. These PM2.5 and PM10 strongly affected the postexercise lung function of students attending these schools.

5. Conclusion

The results of this study showed that students attending schools located near highways are exposed to high concentrations of fine particles both inside and outside classrooms. Exposure to these pollutant particles induced the initiation and exacerbation of EIB among schoolchildren. Effective programs for improving air quality in these schools must be put in place to reduce the deleterious effects of fine particles from vehicle exhaust gases on the respiratory health of school children in the city of Brazzaville.

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Authors' Contribution

F. Nsompi, P.R. Mabounda Kounga, S.I. Moussouami made a significant contribution to the conception of the work. F. Messan, A. Boussana, E.J. Bouhika have revised the article considerably. All authors drafted the work, agreed on all versions of the article prior to submission, and agreed to take responsibility and be responsible for the content of the article. All authors agree to the final version of the manuscript being published.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

[1] Host, S., Chatignoux, E. and Saunal, A. (2012) Impacts sanitaires de la pollution

atmosphérique urbaine et des expositions à proximité du trafic routier dans l'agglomération parisienne. Observatoire régional de santé Île-de-France.

[2] Blondeau, P., Iordache, V., Poupard, O., Genin, D. and Allard, F. (2005) Relationship between Outdoor and Indoor Air Quality in Eight French Schools. *Indoor Air*, **15**, 2-12. https://doi.org/10.1111/j.1600-0668.2004.00263.x

[3] Annesi-Maesano, I., Hulin, M., Lavaud, F., Raherison, C., Kopferschmitt, C., de Blay, F., *et al.* (2012) Poor Air Quality in Classrooms Related Asthma and Rhinitis in Primary Schoolchildren of the French 6 Cities Study. *Thorax*, **67**, 682-688. https://doi.org/10.1136/thoraxjnl-2011-200391

[4] Zhang, Y., He, M., Wu, S., Zhu, Y., Wang, S., Shima, M., *et al.* (2015) Short-Term Effects of Fine Particulate Matter and Temperature on Lung Function among Healthy College Students in Wuhan, China. *International Journal of Environmental Research and Public Health*, **12**, 7777-7793. https://doi.org/10.3390/ijerph120707777

[5] Hwang, B.-F. and Lee, Y.L. (2010) Air Pollution and Prevalence of Bronchitic Symptoms among Children in Taiwan. *Chest*, **138**, 956-964. https://doi.org/10.1378/chest.09-2600

[6] Zwozdziak, A., Sowka, I., Willak-Janc, E., Zwozdziak, J., Kwiecinska, K. and Balinska-Miskiewicz, W. (2016) Influence of PM_1 et $PM_{2.5}$ on Lung Function Parameters in Healthy Schoolchildren—A Panel Study. *Environmental Science and Pollution Research*, **23**, 23892-23901. https://doi.org/10.1007/s11356-016-7605-1

[7] Roy, A., Hu, W., Wei, F., Korn, L., Chapman, R.S. and Zhang, J.J. (2012) Ambient Particulate Matter and Lung Function Growth in Chinese Children. *Epidemiology*, **23**, 464-472. https://doi.org/10.1097/EDE.0b013e31824cbd6d

[8] Badyda, A., Dabrowiecki, P., Czechowski, P. and Majewski, G. (2015) Risk of Bronchi Obstruction among Non-Smokers—Review of Environmental Factors Affecting Bronchoconstriction. *Respiratory Physiology & Neurobiology*, **209**, 39-46. https://doi.org/10.1016/j.resp.2014.10.016

[9] Xu, D., Chen, Y., Wu, L., He, S., Xu, P., Zhang, Y., *et al.* (2020) Acute Effects of Ambient $PM_{2.5}$ on Lung Function among Schoolchildren. *Scientific Reports*, **10**, 4061. https://doi.org/10.1038/s41598-020-61003-4

[10] Bergstra, A.D., Brunekreef, B. and Burdorf, A. (2018) The Effect of Industry-Related Air Pollution on Lung Function and Respiratory Symptoms in Schoolchildren. *Environmental Health*, **17**, 30. https://doi.org/10.1186/s12940-018-0373-2

[11] Aphekom (2011) Improving Knowledge and Communication for Decision Making on Air Pollution and Health in Europe. Summary Report of the Aphekom Project 2008-2011. http://www.systemlife.ro/Studii/Rezumat%20Aphekom.pdf

[12] Gauderman, W.J., Vora, H., Maccnnell, R., Berhane, R., Gilliland, F., Ph Thomas, D., *et al.* (2007) Effect of Exposure to Traffic on Lung Development from 10 to 18 Age—A Cohort. *The Lancet*, **369**, 571-577. https://doi.org/10.1016/S0140-6736(07)60037-3

[13] Messan, F., Lawani, M., Marqueste, T., Lounana, J., Aimiboue, D., Metodakou, A., *et al.* (2011) Evaluation du DEM25 chez 156 enfants exposés à la pollution automobile dans la municipalité de Cotonou. *Mali Médical*, **26**, 16-21.

[14] de Aguiar, K.B. and Anzolin Zhang, L. (2018) Global Prevalence of Exercise-Induced Bronchoconstriction in Children: A Meta-Analysis. *Pediatric Pulmonology*, **53**, 412-425. https://doi.org/10.1002/ppul.23951

[15] Faul, F., Erdfelder, E., Buchner, A. and Lang, A.G. (2009) Statistical Power Analyses Using G*Power 3.1. Tests for Correlation and Regression Analyses. *Behavior Research Methods*, **41**, 1149-1160. https://doi.org/10.3758/BRM.41.4.1149

[16] ERS (The European Respiratory Society) (1993) The Following Chapter Deals with Spirometry, Predicted Values and Bronchodilator Responsiveness: Quanjer, P.H., Jammeling, G.J., Cotes, J.E., Pedersen, O.F., Feslin, R., Yernault, J.C. Lung Volumes and Forced Ventilatory Flows. *European Respiratory Journal*, **6**, 5-40. https://doi.org/10.1183/09041950.005s1693

[17] ATS (American thoracic Society) (1991) Lung Function Testing: Selection of Reference Values and Interpretative Strategies. *American Review of Respiratory Disease*, **144**, 1202-1218. https://doi.org/10.1164/ajrccm/144.5.1202

[18] Ouattara, S., Balayssac-Siransy, A.E., Konaté, A., Tuo N., Keita, M., Dah, C., *et al.* (2012) Bronchospasme induit par l'exercice chez des sportifs de compétition en milieu tropical humide. *Science & Sports*, **27**, 1-8. https://doi.org/10.1016/j.scispo.2011.08.001

[19] Thole, R.T., Sallis, R.E., Rubin, A.L. and Smith, G.N. (2001) Exercise-Induced Bronchospasm Prevalence in Collegiate Cross-Country Runners. *Medicine & Science in Sports & Exercise*, **33**, 1641-1646. https://doi.org/10.1097/00005768-200110000-00005

[20] de Oliveira Costa, R., Silva, J.P., Lacerda, E.M., *et al.* (2016) Overweight Effect on Spirometric Parameters in Adolescents Undergoing Exercise. *Einstein* (*Sao Paulo*), **14**, 190-195. https://doi.org/10.1590/S1679-45082016AO3612

[21] CNSEE (Centre National de la Statistique et des Etudes Economiques) (2011) Annuaire Statistique du Congo 2009.

[22] Xu, D., Zhang, Y., Zhou, L. and Li, T. (2018) Acute Effects of $PM_{2.5}$ on Lung Function Parameters in Schoolchildren in Nanjing, China: A Panel Study. *Environmental Science and Pollution Research*, **25**, 14989-14995. https://doi.org/10.1007/s11356-018-1693-z

[23] Chen, CH., Chan, C.C., Chen, B.Y., Cheng, T.J. and Leon Guo, Y. (2015) Effects of Particulate Air Pollution and Ozone on Lung Function in Non-Asthmatic Children. *Environmental Research*, **137**, 40-48. https://doi.org/10.1016/j.envres.2014.11.021

[24] Wu, S., Deng, F., Hao, Y., Wang, X., Zheng, C., Lv, H., *et al.* (2014) Fine Particulate Matter, Temperature, and Lung Function in Healthy Adults: Findings from the HVNR Study. *Chemosphere*, **108**, 168-174. https://doi.org/10.1016/j.chemosphere.2014.01.032

[25] Strak, M., Boogaard, H., Meliefste, K., Oldenwening, M., Zuurbier, M., Brunekreef, B., *et al.* (2010) Respiratory Health Effects of Ultrafine and Fine Particle Exposure in Cyclists. *Occupational & Environmental Medicine*, **67**, 118-124. https://doi.org/10.1136/oem.2009.046847

[26] Modaresi, M., Kelishadi, R., Amiri, A., *et al.* (2015) The Association of Particulate Matter Air Pollution with Exercise-Induced Bronchospasm. *European Respiratory Journal*, **46**, PA4504. https://doi.org/10.1183/13993003.congress-2015.PA4504

[27] Benarab-Boucherit, Y., *et al.* (2011) Prevalence Rate of Exercise-Induced Bronchoconstriction in Annaba (Algeria) School Children. *Journal of Asthma*, **48**, 511-516. https://doi.org/10.3109/02770903.2011.578315

[28] Keeley, D.J., Neill, P. and Gallivan, S. (1991) Comparison of the Prevalence of Reversible Airways Obstruction in Rural and Urban Zimbabwean Children. *Thorax*, **46**, 549-553. https://doi.org/10.1136/thx.46.8.549

[29] Chen, R., Zhao, A., Chen, H., Zhao, Z., Cai, J., Wang, C., *et al.* (2015) Cardiopulmonary Benefits of Reducing Indoor Particles of Outdoor Origin: A Randomized, Double-Blind Crossover Trial of Air Purifiers. *Journal of the American College of Cardiology*, **65**, 2279-2287. https://doi.org/10.1016/j.jacc.2015.03.553

[30] Guan, T., Hu, S., Han, Y., Wang, R., Zhu, Q., Hu, Y., *et al.* (2018) The Effects of Facemasks on Airway Inflammation and Endothelial Dysfunction in Healthy Young Adults: A Double-Blind, Randomized, Controlled Crossover Study. *Particle and Fibre Toxicology*, **15**, 30. https://doi.org/10.1186/s12989-018-0266-0

[31] Langrish, J.P., Li, J., Wang, S., Lee, M.M., Barnes, G.D., Lei, G.G., *et al.* (2012) Reducing Particulate Air Pollution Exposure in Patients with Coronary Heart Disease Improved Cardiovascular Health. *Environmental Health Perspectives*, **120**, 367-372. https://doi.org/10.1289/ehp.1103898

[32] Langrish, J.P., Lundback, M., Mills, N.L., Johnston, N.R., Webb, D.J., Sandstrom, T., *et al.* (2009) Contribution of Endothelin 1 to the Vascular Effects of Diesel Exhaust Inhalation in Humans. *Hypertension*, **54**, 910-915. https://doi.org/10.1161/HYPERTENSIONAHA.109.135947

[33] Liu, S., Chen, J., Zhao, Q., Song, X., Shao, D., Meliefste, K., *et al.* (2018) Cardiovascular Benefits of Short-Term Indoor Air Filtration Intervention in Elderly Living in Beijing: An Extended Analysis of BIAPSY Study. *Environmental Research*, **167**, 632-638. https://doi.org/10.1016/j.envres.2018.08.026

[34] Pettit, A.P., Kipen, H., Laumbach, R., Ohman-Strickland, P., Kelly-McNeill, K., Cepeda, C., *et al.* (2018) Disrupted Nitric Oxide Metabolism from Type II Diabetes and Acute Exposure to Particulate Air Pollution. *PLOS ONE*, **10**, e0144250. https://doi.org/10.1371/journal.pone.0144250

[35] Yang, X., Jia, X., Dong, W., Wu, S., Miller, M.R., Hu, D., *et al.* (2018) Cardiovascular Benefits of Reducing Personal Exposure to Traffic-Related Noise and Particulate Air Pollution: A Randomized Crossover Study in the Beijing Subway System. *Indoor Air*, **28**, 777-786. https://doi.org/10.1111/ina.12485