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Exercise under Exposure to Air Pollution and Spirometry in Healthy Adults with and without Allergy

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Abstract: Ambient air pollution is a major environmental threat to human health. The acute effects of exposure to ambient air pollution during physical exercise may depend on allergy status. The aim of the study was to assess the acute respiratory responses to air pollution exposure during physical training in young adults with and without allergies. The studied group included 71 healthy young adults (n = 16 with allergy and n = 55 without allergy). Students completed two indoor physical training trials lasting 45–60 min: when air pollutants concentrations were high (exposure trial) and low (control trial). During each trial, we monitored outdoor and indoor environmental conditions. Participants performed spirometry at baseline and directly after the exercise. Exercise during exposure trials led to a small decrease in the percentage of predicted forced expiratory volume in 1 s (FEV_1 ref). Only during the control trials did the FEV_1/forced vital capacity quotient (FEV_1/FVC) statistically significantly increase. Moreover, just in the allergy group, there were statistically significant negative correlations between post-exercise FEV_1/FVC change and 3 h average outdoor particulate matter with aerodynamic diameter <10 µm (PM_{10}) and nitrogen dioxide (NO_2) concentrations (PM_{10}: $r = -0.54$, $p = 0.02$, NO_2: $r = -0.60$, $p = 0.02$). In young and healthy adults, sports training under exposure to high levels of ambient air pollutants leads to a small decrease in FEV_1. The allergy might be a modifying factor in the respiratory responses to air pollution. Post-exercise decrease in FEV_1/FVC was related to pre-exercise 3 h averages of PM_{10} and NO_2 only in people with ever-diagnosed upper-respiratory allergy.

Keywords: air pollution; particulate matter; exercise; spirometry; young adults

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1. Introduction

Ambient air pollution is a major environmental threat to human health. According to the European Environment Agency, it is responsible for approximately 400,000 premature deaths in Europe [1]. Exposure to air pollutants can lead to acute cardiovascular events or exacerbations of chronic respiratory and cardiovascular diseases [2,3]. Children, the elderly, and those with chronic respiratory and cardiovascular diseases are the most vulnerable groups in terms of the negative effects of air pollution [4]. Although young and healthy people are not considered as a risk group, they may be exposed to high levels of air pollutants during active transportation or practicing sport in a polluted urban environment. The absorbed dose of air pollutants during physical exercise increases significantly due to the increase in ventilation [5].

Public health modeling studies point out that in healthy individuals the long-term positive effects of physical activity outweigh the negative impact of air pollution unless the exercises are performed under exposure to extremely high air pollutants concentrations [6,7]. Nevertheless, several studies reported an acute decrease in airflow, expressed as forced expiratory volume in 1 s (FEV_1) and FEV_1/forced vital capacity quotient (FEV_1/FVC) after short-term exposure to air pollution during exercise in healthy adults [8–10].

Induction of both airways and systemic inflammation is one of the key mechanisms that lead to negative health effects of air pollution. The small particles of air pollution can provoke oxidative stress, which may play a role in the health-related aspects [11]. The negative health effect is reflected by the increase of biomarkers of pulmonary and systemic inflammation, such as fractionated nitric oxide (FeNO) and inflammatory cytokines, including interleukin 1 and 6 and tumor necrosis factor (IL-1, IL-6, TNF) [12].

Allergy is a condition that may lead to eosinophilic airways and/or pulmonary inflammation [13]. The prevalence of allergic disorders in developed countries is particularly high. Allergic rhinitis affects approximately 25% of the population in Poland [14]. In the Silesian Voivodeship, which remains the most polluted and urbanized region in the country, the prevalence of allergic disorders is even higher [15]. As shown by a recent publication, skin prick tests in a large group of adolescents showed sensitization to any allergen in 47% of children [15]. Because both allergy and air pollution can increase airway inflammation, allergy might be a modifying factor in the acute responses to air pollution. Nevertheless, its role has not been fully explained. Therefore, we performed a study, the aim of which was to assess the acute respiratory responses (expressed as spirometry parameters) to air pollution exposure during physical training in young adults with and without allergy.

Moreover, the correlation between air pollution and asthma has been investigated and described before [16–19]. Additionally, the link between air pollution and allergic diseases has been suggested; however, this causative relationship has not been well explained and studied. Only some of the studies included a role of the level of physical activity.

2. Materials and Methods

Our study used a case-crossover model and consisted of two training sessions for each participant. The training took place under exposure to different air pollutant levels: high (exposure trial) and low (control trial). For the differentiation of high and low exposure conditions, we used 50 $\mu g/m^3$ of outdoor particulate matter with aerodynamic diameter <10 μm (PM_{10}) concentration recorded at the time of the exercise, based on World Health Organization guidelines (2005 WHO Air quality guidelines offer global guidance on thresholds and limits for key air pollutants that pose health risks, https://www.euro.who.int/__data/assets/pdf_file/0005/78638/E90038.pdf, accessed on 1 July 2021) and EU Air Quality Directive reference value (Directive 2008/50/EC).

The study group was healthy volunteers, comprising students of the Silesian University of Technology who exercised during either obligatory physical education classes (two times per week) or the training of the University Sports Association (Akademicki Związek Sportowy; these students were physically active for two or more hours per day). The exclusion criteria were current infection and any chronic cardiovascular or respiratory diseases, apart from allergies (unless they required anti-allergic drugs at the time of the study or were accompanied by asthma). The participants filled the author's qualification questionnaire containing questions on health status, physical activity patterns, and place of residence and housing conditions. Questions on allergy included declaration of allergy ever diagnosed by a doctor (according to this, the participants were divided into allergy or no-allergy groups), if it is to airborne allergens, and the symptoms of allergy. In addition, we asked whether the participant suffered from allergy symptoms or required anti-allergic medication up to one month prior to the study, which was among exclusion criteria. From 141 students invited to the study, 90 agreed to participate. After excluding the participants who completed only one training trial or whose spirometry did not meet acceptability or repeatability criteria, the results of 71 participants were further analyzed.

All training trials took place between November 2019 and March 2020 indoors in one of the university's sports halls, close to Gliwice city center. The city of Gliwice is a part of the Upper Silesian Agglomeration, a densely populated area in the south of Poland. The region is characterized by high levels of ambient air pollutants, especially during the cold season (November–March). In 2018, the average annual level of PM_{10} was 40 $\mu g/m^3$ [20]. During the training, we recorded indoor $PM_{2.5}$ and PM_{10} using SidePak AM520 (TSI, Shoreview, MN, USA). In addition, we controlled outdoor air conditions during the exercise time and up to 3 h earlier with the use of a mobile laboratory located at the university campus. It provided complex data on ambient sulfur dioxide (SO_2) and nitric dioxide (NO_2) with T100 and T200 devices (Teledyne Advanced Pollution Instrumentation, San Diego, CA, USA), particulate matter with BAM1020 (MetOne Instruments, Grants Pass, OR, USA), and weather conditions with WS500 (Lufft, Fellbach, Germany).

The investigators did not influence the type and intensity of the physical exercise. Each participant exercised according to the normal schedule. For physical education classes, the most common activities were volleyball and basketball and, for the University Sports Association training, volleyball, basketball, and judo. Before the training, the participants filled a short qualification questionnaire and were measured and weighed. Then, the investigators took the baseline health measurements: blood pressure, fractionated exhaled nitric oxide (FeNO), and spirometry. Spirometry was performed according to the American Thoracic Society (ATS) and the European Respiratory Society (ERS) guidelines in a sitting position with the Easy One Air device (NDD, Zurich, Switzerland). The participants repeated the maneuvers to meet the acceptability and repeatability criteria. If a participant reached the maximal number of maneuvers (8) without meeting the criteria, the data of the participant were excluded from further analysis. After completing the baseline measurements, the volunteers participated in the training. After 45–60 min of exercise, they were asked to return to the health measurement room, where the same measurements (blood pressure, FeNO, and spirometry) were repeated immediately.

We performed the statistical analysis with Statistica software (version 13.3, TIBCO Software Inc., Palo Alto, CA, USA). The normality of the distribution of quantitative variables was assessed with the Shapiro–Wilk test. The differences in environmental conditions between exposure and control trials were analyzed with Mann–Whitney U-test. For paired health measurements, we used the paired t-test or the Wilcoxon test. The relative differences were presented as percentages ('post-exercise'-'baseline'/'baseline'). The correlations between relative differences in health measurements and environmental conditions were analyzed with the Spearman rank correlation. The Fisher test was used for the comparison of qualitative variables.

The study design has also been described in detail in our previous paper, which focused on FeNO [21]. The study protocol was accepted by the Ethics Committee of the Medical University of Silesia in Katowice, Agreement PCN/0022/KB1/125/I/19, from 3 December 2019.

3. Results

Seventy-one participants completed two exercise trials in the conditions of high and low ambient air pollution (exposure and control trial). Participants were healthy students (average age = 20.7 years). Thirty-six participants attended University Sports Education training (high level of physical activity), while 35 exercised only during obligatory physical education classes (low level of physical activity). Among the study group, 16 volunteers suffered from allergy (self-declared in the qualification questionnaire): allergic rhinitis and/or conjunctivitis. The allergies were to airborne allergens such as pollens and dust mites. None of the participants had allergy symptoms nor required anti-allergic medication during the study period. Table 1 shows the basic characteristics of the study group.

Table 1. Anthropometric variables, physical activity patterns, and allergy status of the study group (n = 71).

Quantitative Variable		X ± SD
Age (years)		20.7 ± 2.6
Height (cm)		177.1 ± 9.5
Body mass (kg)		73.3 ± 15.9
BMI (kg/m^2)		23.2 ± 4.0
Qualitative Variable		***n* (%)**
Sex	Female	28 (39.4)
	Male	43 (60.6)
Place of residence	Village or city < 100,000 inhabitants	21 (29.6)
	City ≥ 100,000 inhabitants	50 (70.4)
Physical activity *	Low	35 (49.3)
	High	36 (50.7)
Allergy	No	55 (77.5)
	Yes	16 (22.5)

X—arithmetic mean, SD—standard deviation, N—number, * Low—students exercising only during obligatory physical education classes, High—players training in the University Sports Association's training (AZS—Akademicki Związek Sportowy).

During the exposure trials, the concentrations of all controlled air pollutants were statistically significantly higher and temperatures lower than during the control trials. Table 2 presents the comparison of environmental conditions recorded during the exercise trials, as well as 3 h average concentrations of air pollutants from the time before the study.

Table 2. Distribution of environmental conditions recorded during and before the training (n = 71).

Environmental Factor	Exposure Trials		Control Trials		p **
	Me	IQR	Me	IQR	
TEM_{IN} (°C)	21.7	20.9–22.4	22.0	20.8–22.6	0.02
$PM_{2.5\ IN}$ ($\mu g/m^3$)	114.0	86.0–170.0	27.0	18.6–29.0	<0.001
$PM_{10\ IN}$ ($\mu g/m^3$)	155.2	101.2–200.0	45.3	21.9–49.0	<0.001
TEM_{OUT} (°C)	2.6	0.6–5.1	5.0	2.3–12.4	<0.001
PM_{10} ($\mu g/m^3$)	127.3	86.4–149.0	33.4	29.1–45.9	<0.001
SO_2 ($\mu g/m^3$)	26.2	20.3–32.7	18.3	7.2–21.1	<0.001
NO_2 ($\mu g/m^3$)	50.6	40.0–53.2	29.3	19.5–37.9	<0.001
3 h * PM_{10} ($\mu g/m^3$)	154.8	62.5–210.8	19.7	10.3–50.5	<0.001
3 h * SO_2 ($\mu g/m^3$)	31.1	20.5–38.8	18.0	13.5–27.0	<0.001
3 h * NO_2 ($\mu g/m^3$)	50.1	41.0–51.4	21.3	18.4–28.0	<0.001

Me—median value, IQR—interquartile range, TEM_{IN} and TEM_{OUT}—indoor and outdoor temperature, $PM_{2.5IN}$—indoor concentration of particulate matter with diameter < 2.5 µm, $PM_{10\ IN}$—indoor concentration of particulate matter with diameter < 10 µm, PM_{10}—outdoor concentration of particulate matter with diameter < 10 µm, SO_2—sulfur dioxide, NO_2—nitrogen dioxide, 3 h *—average concentrations from 3 h before the training (3 h lag), p **—results of Mann–Whitney U-test.

The spirometry results obtained in the participants were within normal values. During both exposure and control conditions, the forced vital capacity (FVC) decreased statistically significantly after the exercise. Exercise during exposure trials led to a small decrease in the percentage of predicted forced expiratory volume in 1 s (FEV_1 ref). Only during the control trials did FEV_1/FVC slightly but statistically significantly increase. The spirometry results during exposure and control exercise trials are presented in Table 3.

Table 3. Spirometry results noted during exposure and control trials (n = 71).

Variable	Exposure Trials Baseline X ± SD	Exposure Trials Post-Exercise X ± SD	p *	Control Trials Baseline X ± SD	Control Trials Post-Exercise X ± SD	p *
FVC (L)	4.87 ± 1.0	4.82 ± 1.0	0.01	4.84 ± 0.97	4.80 ± 0.99	0.03
FEV_1 (L)	4.18 ± 0.75	4.16 ± 0.76	0.08	4.12 ± 0.74	4.13 ± 0.74	0.7
FEV_1/FVC (%)	86.59 ± 6.16	86.82 ± 6.48	0.4	85.76 ± 6.28	86.65 ± 6.39	0.002
$FEF_{25–75}$ (L/s)	4.47 ± 1.02	4.57 ± 1.02	0.007	4.66 ± 0.98	4.60 ± 0.98	0.3
FVC ref	95.88 ± 12.64	94.86 ± 12.08	0.004	95.22 ± 11.87	94.41 ± 12.16	0.02
FEV_1 ref	96.75 ± 11.20	96.01 ± 11.09	0.04	95.16 ± 10.28	95.32 ± 10.80	0.6
FEV_1/FVC ref	100.52 ± 6.26	100.77 ± 6.56	0.4	99.55 ± 6.47	100.77 ± 6.56	0.002

X—arithmetic mean, SD—standard deviation, FVC—forced vital capacity, FEV_1—forced expiratory volume in 1 s, FEV1/FVC—quotient FEV_1/FVC, $FEF_{25–75}$—forced expiratory flow at 25–75% of forced vital capacity, ref—the percentage of predicted value according to GLI equations, p *—results of paired Student's t-test/Wilcoxon test.

Table 4 shows the comparison of allergy (n = 16) and no-allergy groups (n = 55). There were no statistically significant differences in terms of anthropometric parameters, sex, and air pollutant concentrations recorded during the exposure trials.

Table 4. Basic comparison of no-allergy (n = 55) and allergy (n = 16) groups.

Variable	No Allergy (n = 55)	Allergy (n = 16)	p **
Age (years)	20.0 (2.0)	20.0 (2.5)	0.9
BMI (kg/m^2)	22.8; (4.8)	23.1 (3.6)	0.3
Sex (Female)	28; 51%	6; 38%	0.2
Physical Activity (High)	24; 44%	4; 25%	0.2
TEM $_{IN}$ (°C)	21.7 (1.2)	21.5 (1.5)	0.7
TEM $_{OUT}$ (°C)	1.6 (4.0)	1.8 (5.1)	0.6
$PM_{2.5\ IN}$ (µg/m^3)	114.0 (100.0)	117.5 (60.0)	0.8
3 h * PM_{10} (µg/m^3)	143.7 (148.3)	160.9 (78.1)	0.2
3 h * NO_2 (µg/m^3)	49.3 (25.1)	50.9 (3.3)	0.3

3 h *—average concentrations from 3 h before the training (3 h lag), p **—results of Student's t-test/Mann–Whitney U-test/Fisher test (for qualitative variables); values in the table are: 'median (interquartile range)' for quantitative values and 'number; percentage' for qualitative values.

Comparison of post-exercise changes in spirometry parameters (relative differences) between exposure and control trials separately for the no-allergy and allergy groups is shown in Table 5. In the case of participants without allergy, there were no statistically significant differences. Only in the allergy group did FEV_1/FVC increase statistically significantly more during control trials than during exposure trials.

Table 5. Comparison of post-exercise changes in spirometry parameters (relative differences) between exposure and control trials for no-allergy (n = 55) and allergy (n = 16) groups.

Variable	Relative Difference (%) between Post-Exercise and Baseline Measurements: No Allergy (n = 55) Exposure X ± SD	No Allergy (n = 55) Control X ± SD	p *	Allergy (n = 16) Exposure X ± SD	Allergy (n = 16) Control X ± SD	p *
FVC	−0.9 ± 3.1	−1.0 ± 3.2	0.9	−1.2 ± 3.1	−0.3 ± 2.6	0.4
FEV_1	−0.6 ± 3.1	−0.4 ± 3.4	0.8	−1.0 ± 3.8	2.0 ± 3.4	0.05
FEV_1/FVC	0.3 ± 2.9	0.7 ± 3.0	0.3	0.2 ± 2.3	2.3 ± 1.9	0.007
$FEF_{25–75}$	1.4 ± 8.3	−1.0 ± 6.4	0.1	6.1 ± 6.0	−1.1 ± 9.0	0.01

X—arithmetic mean, SD—standard deviation, FVC—forced vital capacity, FEV_1—forced expiratory volume in 1 s, FEV1/FVC—quotient FEV_1/FVC, forced expiratory flow at 25–75% of forced vital capacity, p *—results of paired Student's t-test/Wilcoxon test.

The correlation analysis showed that only in the allergy group, there were statistically significant negative correlations between post-exercise FEV_1/FVC change and 3 h average outdoor PM_{10} and NO_2 concentrations (PM_{10}: $r = -0.54$, $p = 0.02$, NO_2: $r = -0.60$, $p = 0.02$).

No statistically significant correlations were found for concentrations recorded during the exercise or for concentrations recorded during the control trials. Table 6 shows detailed results of the correlation analysis.

Table 6. Correlations between post-exercise change in FEV_1/FVC and environmental conditions (results of Spearman rank test; the table presents results as R (*p*-value)).

Environmental Factor	ΔFEV$_1$/FVC No Allergy (*n* = 55) Exposure	Control	Allergy (*n* = 16) Exposure	Control
TEM_{IN} (°C)	−0.12 (0.3)	−0.02 (0.8)	−0.37 (0.1)	−0.05 (0.8)
$PM_{2.5\ IN}$ (μg/m^3)	0.19 (0.1)	0.00 (0.9)	0.02 (0.9)	−0.01 (0.9)
$PM_{10\ IN}$ (μg/m^3)	0.23 (0.09)	0.07 (0.5)	−0.01 (0.9)	0.02 (0.9)
TEM_{OUT} (°C)	−0.12 (0.3)	−0.07 (0.6)	0.21 (0.4)	−0.04 (0.8)
PM_{10} (μg/m^3)	0.12 (0.3)	−0.07 (0.5)	−0.31 (0.2)	0.02 (0.9)
SO_2 (μg/m^3)	0.04 (0.7)	−0.15 (0.2)	−0.34 (0.1)	0.36 (0.1)
NO_2 (μg/m^3)	0.18 (0.1)	−0.16 (0.2)	−0.12 (0.6)	−0.06 (0.8)
3 h * PM_{10} (μg/m^3)	0.04 (0.7)	−0.24 (0.08)	−0.54 (0.02)	0.03 (0.9)
3 h * SO_2 (μg/m^3)	−0.14 (0.3)	0.04 (0.7)	0.14 (0.6)	0.04 (0.8)
3 h * NO_2 (μg/m^3)	0.18 (0.3)	−0.18 (0.1)	−0.60 (0.02)	−0.03 (0.9)

TEM_{IN} and TEM_{OUT}—indoor and outdoor temperature, $PM_{2.5IN}$—indoor concentration of particulate matter with diameter < 2.5 μm, $PM_{10\ IN}$—indoor concentration of particulate matter with diameter < 10 μm, PM_{10}—outdoor concentration of particulate matter with diameter < 10 μm, SO_2—sulfur dioxide, NO_2—nitrogen dioxide, 3 h *—average concentrations from 3 h before the training (3 h lag).

4. Discussion

Our results showed differences between the respiratory responses to exercise under different air pollution exposure conditions. A small but statistically significant decrease in FEV_1 was present only after exercise under exposure to high levels of air pollutants (exposure trials). The negative impact of exposure to air pollutants during exercise on spirometry parameters was previously observed both in people suffering from chronic diseases [22] and in healthy adults [8–10,23]. Other studies indicate that physical activity has the potential to alleviate the negative impact of air pollution at low air pollutant levels [23,24]. In our study, FEV_1/FVC increased only after exercise in low air pollution settings (control trials).

On the other hand, some studies in healthy adults did not report acute deterioration in respiratory function after exercises in exposure conditions [25,26]. Those discrepancies might be partly due to different exposure conditions. The available research on interactions between physical activity and air pollution comes mostly from high-income countries that are characterized by better air quality. Still, there are scarce data from middle- and low-income countries [5,27]. Our study took place in a region facing severe air pollution episodes during colder seasons (winter). Ambient particulate matter concentrations recorded on the days of exposure trials significantly exceeded European and WHO standards. This enabled us to observe effects that would probably not be present in cleaner conditions.

Another finding of the study is that only in participants with an upper-respiratory allergy (defined as allergic rhinitis and/or conjunctivitis) the post-exercise changes in FEV_1/FVC differed significantly between exposure and control trials (0.2 vs. 2.3% increase during exposure and control trials, respectively). Additionally, statistically significant correlations between post-exercise changes in FEV_1/FVC and 3 h averages of PM_{10} and NO_2 were present only in subjects with allergies. Allergic rhinitis, the most common allergic disorder in our study group, is connected with the inflammatory process within nasal mucosa [28]. By sharing inflammatory pathophysiology, allergy might affect respiratory responses to air pollution. People with allergies may be more susceptible to negative airflow changes induced by exposure to air pollutants during exercise. It has been also shown that atopy is one of the key risk factors of exercise-induced bronchospasm [29]. This can further exacerbate bronchoconstriction induced by air pollutants.

On the other hand, it was shown that black carbon (BC) strongly correlated with FeNO, a marker of pulmonary inflammation, only in children without atopy. In those with atopy, FeNO was related to household dust mite allergens levels instead [30]. This led to a hypothesis that the strong allergic component of airways inflammation outweighs the milder influence of air pollution [30]. Nevertheless, only a few research addressed the impact of allergy on the respiratory responses to air pollution exposure during exercise. The author's previous study showed different responses in terms of FeNO in young males with and without upper-respiratory allergy doing short intensive exercise on a cycle ergometer [31]. Only in subjects without allergy did post-exercise changes in FeNO correlate with air pollutants concentrations recorded during exercise. However, the continuation of the same study showed that, in healthy males, only the air pollutants levels were determinants of post-exercise airflow decline (decrease in FEV_1/FVC) [8]. Still, more studies with different study protocols are needed to explain the impact of upper-respiratory allergy on the respiratory responses to air pollution exposure during exercise.

Interestingly, we only found statistically significant correlations for average concentrations of outdoor PM_{10} and NO_2 from 3 h before the study. No statistically significant correlations were found for indoor concentrations. One of the explanations for this fact is that negative respiratory responses to air pollution may require more time to develop. In this scenario, the cumulative exposure from the day of the exercise trial might have a larger impact than the short exposure during exercise. Exposure to NO_2 and PM_{10}, among other mechanisms, induces respiratory and systemic inflammation, which later may lead to changes in airflow [4,12]. Development of this response may require more time. On the other hand, we measured only acute post-exercise responses. For example, Kubesch et al. observed an increase in FeNO only 30 min after exercises in high traffic-related air pollution (TRAP) conditions and not directly after the exercise [32]. We cannot exclude that the impact of indoor exposure could be observed if we repeated the measurements after some amount of time.

The strength of the study is that it was conducted in a relatively large group of young adults who were examined twice, during different exposure conditions. Instead of using laboratory settings, the exercise included real-life activities according to the participants' schedules. This made the results more corresponding to real-world exposures. Another advantage is the study site, which lets us study the impact of exposure to high levels of air pollution.

The study also has several limitations. First of all, the allergy was defined based on participants' declarations in the questionnaire. We asked in the questionnaire, whether the allergy was confirmed by the doctor and only such cases were considered. Nevertheless, we cannot exclude the bias of underdiagnosed allergy in the no-allergy group or underdiagnosed asthma in the allergy group. Future studies shall use more accurate ways of allergy group definition, for example by blood IgE levels. Another limitation is that we limited the health measurements to two points: baseline and directly after exercise. Repeating the measurements after some time would help to define whether observed airflow changes are long lasting. In addition, it might lead to the observation of effects that have a longer time lag after the exposure. Additionally, what may affect the meaning of the correlations between FEV1/FVC and 3 h average air pollutants concentrations is that we cannot exclude that some participants were exposed to different concentrations. However, most of the participants lived in Gliwice and neighboring cities. Moreover, only 10 of them (2 with and 8 without allergy) started their daily schedule with training. The rest had their classes at the campus before the physical education/sports training and were exposed to the exact concentrations measured on-site. We believe that this reduces the potential bias.

5. Conclusions

In this study, we found that in young and healthy adults, sports training under exposure to high levels of ambient air pollutants leads to a small decrease in FEV_1. The allergy might be a modifying factor in the respiratory responses to air pollution. Post-exercise decrease in FEV_1/FVC was related to pre-exercise 3 h averages of PM_{10} and NO_2 only in people with ever-diagnosed upper-respiratory allergy.

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Institutional Review Board Statement: The study was conducted according to the guidelines of the Declaration of Helsinki and approved by the Ethics Committee of the Medical University of Silesia in Katowice (Agreement PCN/0022/KB1/125/I/19 from 3 December 2019).

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: The data are available on request from the Department of Epidemiology, Medical University of Silesia in Katowice. The request should be formulated and sent to epikat@sum.edu.pl.

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