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Assessing the Influence of Vehicular Traffic-Associated Atmospheric Pollutants on Pulmonary Function Using Spirometry and Impulse Oscillometry in Healthy Participants: Insights from Bogotá, 2020–2021

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Abstract: Air pollution, particularly from particulate matter ($PM_{2.5}$) and black carbon (eBC), has been implicated in airway pathologies. This study aims to assess the relationship between exposure to these pollutants and respiratory function in various populations, including healthy individuals, while seeking an accurate assessment method. A cross-sectional study was conducted in Bogotá, evaluating respiratory function in the users of bicycles, minivans, and buses through spirometry and impulse oscillometry. Measurements were taken along two main avenues, assessing the $PM_{2.5}$ and eBC concentrations. The results reveal higher pollutant levels on AVE KR 9, correlating with changes in oscillometry values post-travel. Cyclists exhibited differing pre- and post-travel values compared to bus and minivan users, suggesting aerobic exercise mitigates pollutant impacts. However, no statistically significant spirometry or impulse oscillometry variations were observed among routes or modes. Public transport and minivan users showed greater $PM_{2.5}$ and eBC exposure, yet no significant changes associated with environmental contaminants were found in respiratory function values. These findings underscore the importance of further research on pollutant effects and respiratory health in urban environments, particularly concerning different transport modes.

Keywords: impulse oscillometry; spirometry; $PM_{2.5}$; black carbon; public health

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1. Introduction

Numerous studies have examined the impact of air pollutants on human health, with a particular focus on particulate matter ($PM_{2.5}$) and black carbon (eBC) [1–3]. Exposure to $PM_{2.5}$ and eBC has also been linked to an increased risk of cardiovascular diseases, such as heart attacks, strokes, and high blood pressure. Prolonged exposure to these pollutants has been associated with a higher mortality rate, especially among vulnerable populations like the elderly, children, and individuals with pre-existing respiratory or cardiovascular conditions [4,5]. However, urban environments often have short-term, high-concentration exposure to these pollutants, leading to changes in the respiratory system, which can result in increased respiratory infections and asthma exacerbations, particularly in susceptible populations [6,7]. These changes are mediated by the irritative effects on the airways [8–10].

Nevertheless, there is limited evidence regarding the short-term effects of $PM_{2.5}$ and eBC exposure on healthy participants. Findings from the ITHACA study, conducted in four corridors of Bogota and involving three different transport modes, indicated that $PM_{2.5}$ and eBC concentrations were the highest in buses and minivans compared to bicycles ($p < 0.05$) [11]. However, the ITHACA study did not observe any effects on spirometry volumes among the participants, raising the question of whether spirometry is sensitive enough to evaluate the short-term effects of $PM_{2.5}$ and eBC on lung function [11–13].

Some authors have suggested that impulse oscillometry may be a more suitable test for evaluating changes in the airways associated with pollutant exposure [14,15]. The present study aimed to assess the effects of exposure on respiratory function (spirometry and impulse oscillometry) among a group of healthy users of three different transport modes in Bogota.

2. Materials and Methods

We conducted a cross-sectional study aiming to assess respiratory function of individuals exposed to $PM_{2.5}$ and eBC using three different modes of transportation: bicycles, minivans, and buses.

2.1. Population and Study Area

Ten participants voluntarily agreed to travel by bicycle, minivan, and bus on different routes from August 2021 to December 2021. The participants were recruited from the Air Contamination And Health Effects in Microenvironments in Bogota (ITHACA) study [11].The study included men and women between 18 and 54 years of age who were nonsmokers and had no history of chronic noncommunicable diseases. For more details, please refer to the Protocol for a Mixed-Methods Study (ITHACA) on the Assessment of Personal Exposure to Particulate Air Pollution in Different Microenvironments and Traveling by Several Modes of Transportation in Bogota, Colombia [11].

The measurements were conducted on two routes in the northern zone of the urban area of Bogota: Avenida Carrera 9 (AVE KR 9) from Calle 161 to Calle 127 and Carrera 19 (KR 19) between streets 161 and 134 (Figure 1). The selection of these routes was based on three criteria agreed upon with the Secretaria Distrital of Mobility: (i) roads with high daily vehicular traffic (including bicycles, minivans, and regular buses) in the Integrated Public Transport System (SITP); (ii) routes with dedicated bike paths; and (iii) pathways that had not been previously monitored in similar studies.

2.2. Type of Study and Sample Size

We conducted a non-probabilistic study focused on measurements (number of trips) rather than individuals. To determine the sample size, we formulated a one-sided hypothesis to detect a difference in means greater than zero. The significance level was set at $\alpha = 0.05$, and we aimed for a target power of $(1 - \beta) = 0.80$, with a margin of error of $\beta = 0.20$. Considering a constant of K = 6.3 and a minimum difference of 0.55 deemed significant in R5 ($\mu 1 - \mu 2$), we assumed a standard deviation (σ) of 1.1 in each group. To conduct this study, a minimum sample size of 50 trips was estimated.

2.3. Measurement of Concentrations of Particulate Matter Less Than 2.5 ($PM_{2.5}$) and Black Carbon

$PM_{2.5}$ measurements were performed using The SidePak™ AM520 (SP) personal aerosol monitor was manufactured by TSI Incorporated, which is headquartered in Shoreview, Minnesota, United States.The mass concentration of $PM_{2.5}$ was measured at 1 Hz using a laser scattering-based method. These instruments utilize laser wavelengths of 780 and 640, respectively [16]. The size selection of the sampled particles was achieved through an inertial impactor located at the instrument inlet. Flow calibration was performed before each use to ensure proper selection of particle aerodynamic size. A thorough comparison among three SP instruments used in this study was conducted in a laboratory environment prior to the campaign. The instruments exhibited excellent agreement, with data averaged every 30 s showing a correlation coefficient of 0.90. The bias between the instruments was estimated at 15%.

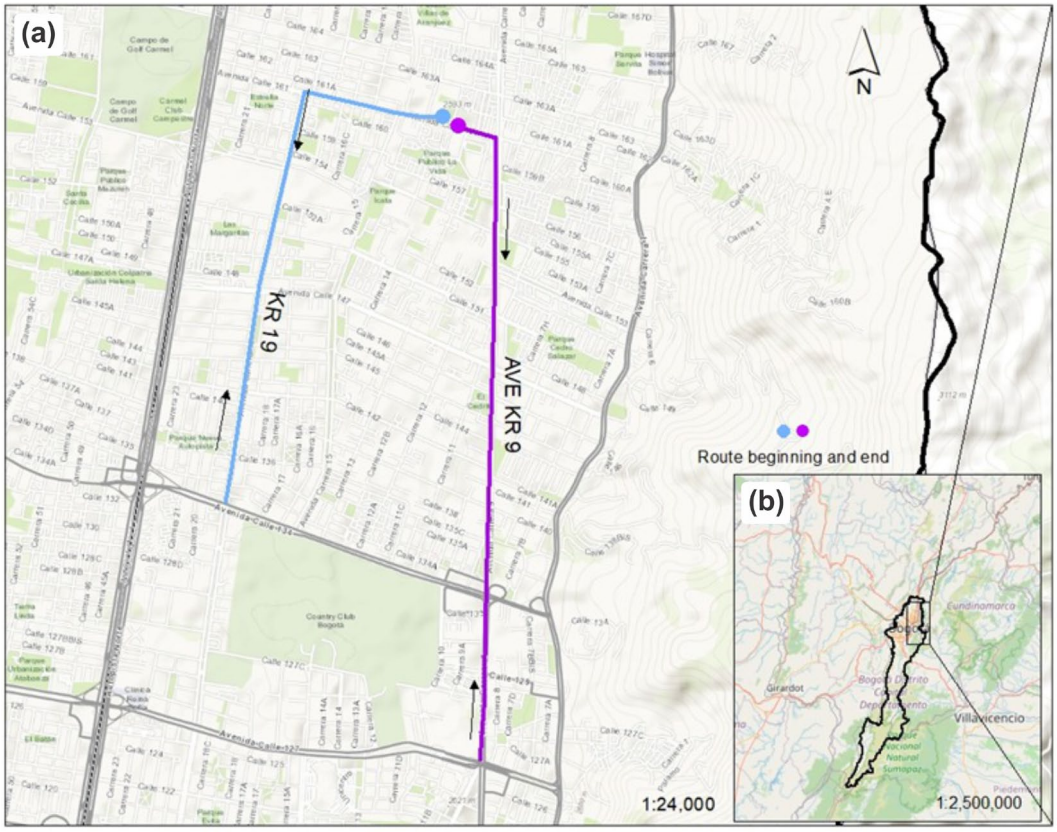

Figure 1. (**a**) Spatial location of Bogotá and (**b**) Location of the two (2) routes monitored in the northern zone of the city of Bogotá. The dots indicate the start and end points of the parallel routes.

eBC was measured using a MicroAeth AE51 (MicroAeth AE51, AethLabs, San Francisco, CA, USA). Raw data were corrected for low atmospheric pressure in Bogotá. The nominal flow rate was set at 150 cm^3 min^{-1}. Corrections were applied for filter loading effects using a linear correction method. Simultaneous measurements with different levels of attenuation were used to infer the loading correction constant. The reported accuracy of the instrument was +/− 100 ng m^{-3}. Data were reported as 30 s averages, with a maximum attenuation of 140. Filters exceeding this maximum were used to infer the loading factor, and corrected data from less-loaded instruments were used for reporting concentrations [16].

More detailed information related to the calibration and review methods were described in a previously published protocol and prior studies [11].

2.4. Measurement of Pulmonary Function

Two tests were applied to measure the lung function of the participants: Impulse oscillometry and spirometry. Both tests were performed before the start of travel (pre-travel) and at least two hours after having completed travel (post-travel). At least three repetitions of each of the tests were applied by a respiratory therapist. The selection of the best spirometry and oscillometry tests was performed according to the recommendations and criteria of the American Thoracic Association [17].

2.5. Selected Variables

According to the literature review, we included variables from spirometry and impulse oscillometry tests. Some authors have proposed that the difference between pre- and post-travel FEV1/FVC spirometry values is associated with short- to medium-term exposure to $PM_{2.5}$ [18]. Additionally, it has been highlighted that it is possible to estimate changes in the resistance to air in the small airway (R5) related to short-term exposure to $PM_{2.5}$ [19].

In addition, it has been indicated that the increase in the difference between the peripheral (R5) and central resistance to air (D20) may be associated with exposure to particulate matter [16].

2.6. Statistical Analysis

A correlation of paired data was performed using a Wilcoxon test to analyze whether there were significant relationships between lung function test values and their possible alterations in relation to exposure to atmospheric pollutants. Total measurements were used for statistical analysis, showing the median as a measure of central tendency and an interquartile range.

2.7. Ethical Considerations

The study was conducted in accordance with the Declaration of Helsinki for studies involving humans. It considered the International Ethical Guidelines for Health-related Research Involving Humans. The protocol was approved by the Research Ethics and Methodologies Committee (CEMIN) at the National Institute of Health of Colombia (protocol code 014/2019).

3. Results

The study included 10 volunteers who completed 50 trips. Their average age was 31 years, and 60% (n = 6) were women. The average body mass index (BMI) was 23. Seven volunteers used all transportation modes; one used a minivan and bus; one used only a minivan; and one used a bicycle, with a total of 25 trips per route. The distribution of the participants was duplicated because exposure was measured for participants on both routes, with a total of 50 trips included in the study.

It was observed that the route with the highest concentrations of $PM_{2.5}$ and eBC was the AVE KR 9 ($\tilde{x}$ =17.43 μg/m^3; σ = 37.2 μg/m^3 and 6.68 μg/m^3; σ = 14.8 μg/m^3, respectively) (Figure 2). This result was similar between the routes for $PM_{2.5}$ in participants using a bus and bicycle for transportation ($\tilde{x}$ = 15.71 μg/m^3; σ = 59.3 μg/m^3 and 20.08 μg/m^3; σ = 51.7 μg/m^3, respectively). However, for participants using minivans, the highest concentrations of $PM_{2.5}$ were observed on KR 19 ($\tilde{x}$ = 19.93 μg/m^3; σ = 53.9 μg/m^3). The highest concentrations of eBC were recorded on buses on KR 19 ($\tilde{x}$ = 6.49 μg/m^3; σ = 37.01 μg/m^3) and bicycles on AV KR 9 ($\tilde{x}$ = 7.69 μg/m^3; σ = 30.3 μg/m^3) due to the traffic and cycling infrastructure.

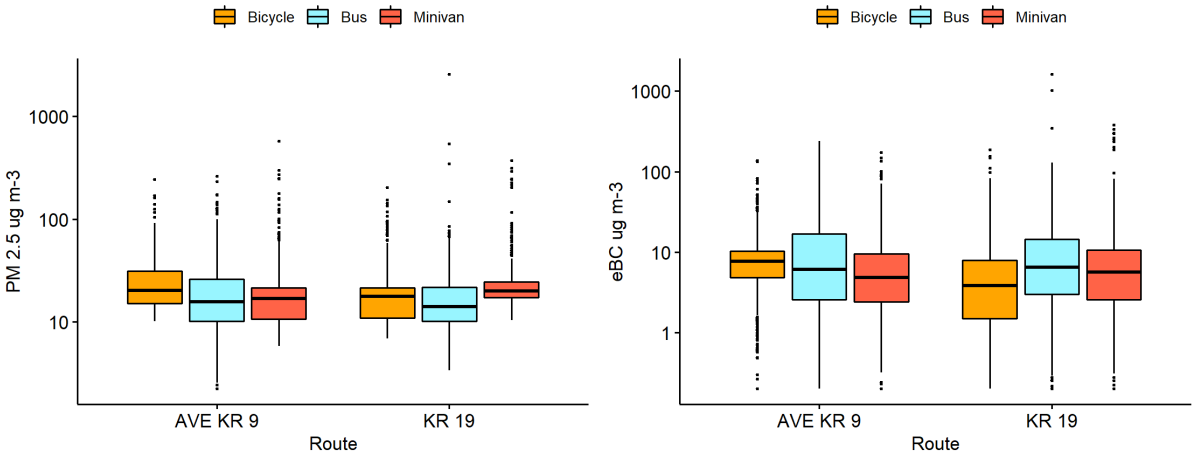

Figure 2. Concentrations of $PM_{2.5}$ (**left** panel) and eBC (**right** panel) by transportation modes and routes.

Respiratory Function Tests

There were no significant clinical changes in spirometry parameters across the routes and modes of transportation. The spirometry tests showed similar FEV1/FVC values before

and after travel, and these values were consistent across different modes of transportation (Figures 3 and 4). The Wilcoxon test results for pulmonary function parameters were non-significant for both routes and all transportation modes (Table 1).

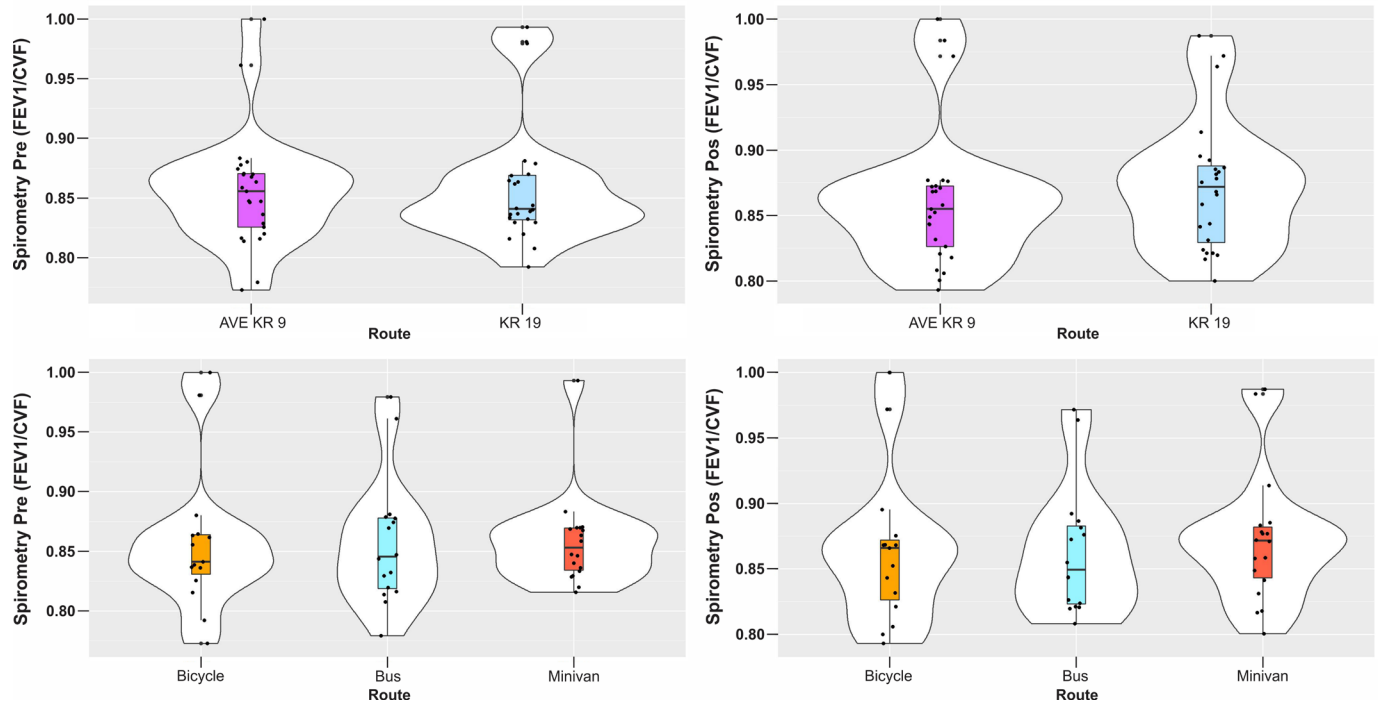

Figure 3. Pre- and post-travel FEV1/FVC spirometry values by route and mode of transportation.

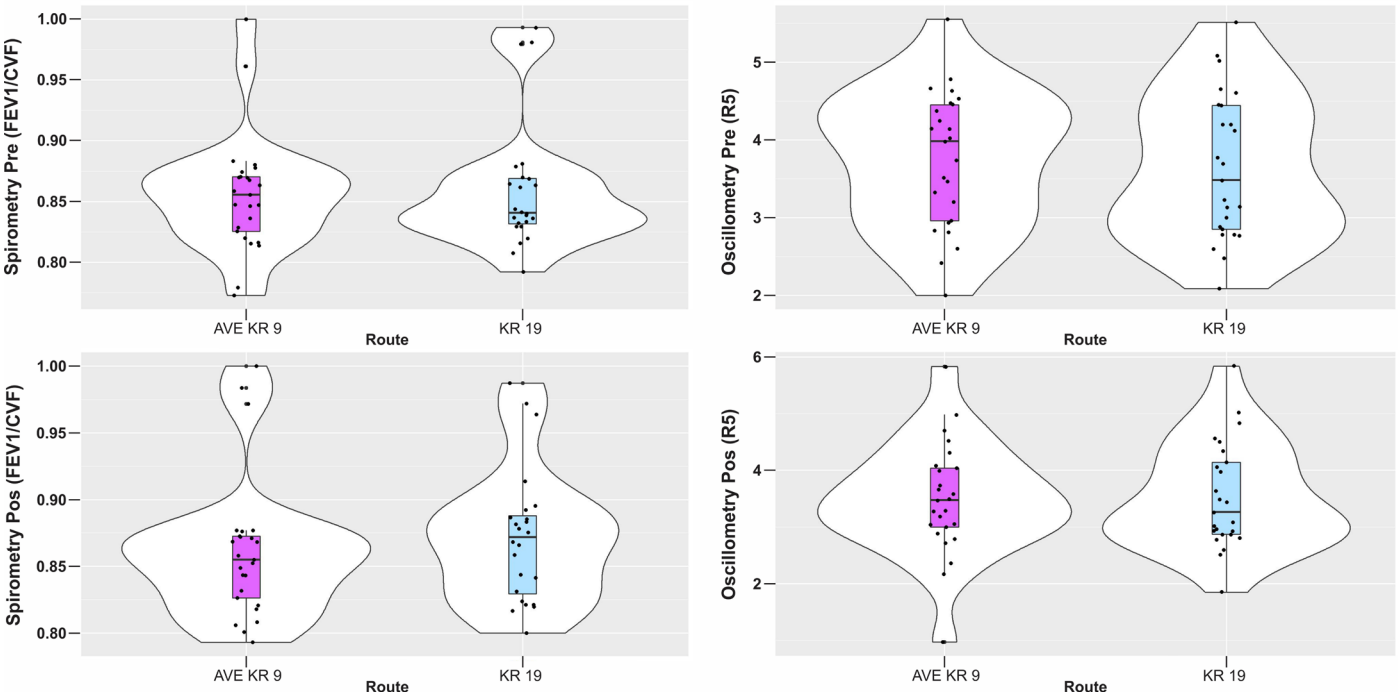

Figure 4. Comparison of pre- and post-travel FEV1/FVC spirometry values and pre- and post-travel R5 oscillometry values.

Table 1. Medians and Wilcoxon tests of spirometry and impulse oscillometry variables (post-travel values).

		Minivan	Bicycle	Bus	*p*
FVC	AVE KR 9	3.46	3.48	3.46	0.97
	KR 19	3.4	3.4	3.38	0.92
FEV_1	AVE KR 9	3.02	3.01	3.08	0.94
	KR 19	3.09	3.06	2.96	0.72
D5-20	AVE KR 9	15.72	17.79	13.38	0.64
	KR 19	14.33	9.765	12.715	0.25

The R5 and D5-20 values showed no significant differences based on sex, and there were no notable variations in the post-examination responses between the different routes (mean = 12.27 Hz; σ = 8.7 HZ for KR 19 and 15.63 Hz; σ = 8.8 HZ for AVE KR 9). It is important to highlight that 18% (n = 9) of the participants exhibited increased peripheral resistance values (R5 and R20/R5) during the pre-test impulse oscillometry, and this was not linked to the specific route or the participants' sex ($p > 0.05$) (Figure 4). However, post-test peripheral resistance only improved in 22% (n = 2/9) of the participants who initially had elevated peripheral resistance values (R5 and R20/R5). These changes were also not associated with the route or mode of transportation ($p > 0.05$).

The median D5-20 values for the three transportation modes (bicycles, buses, and minivans) were similar (mean = 13.78 Hz; σ = 10.16 HZ, 13.05 Hz; σ = 8.3 HZ, and 15.03 Hz; σ = 7.6 HZ, respectively) (Figure 5). Notably, the subjects using bicycles showed consistent pre- and post-travel values, whereas those using buses and minivans tended to have increased post-travel values, but the changes were not statically relevant ($p > 0.05$).

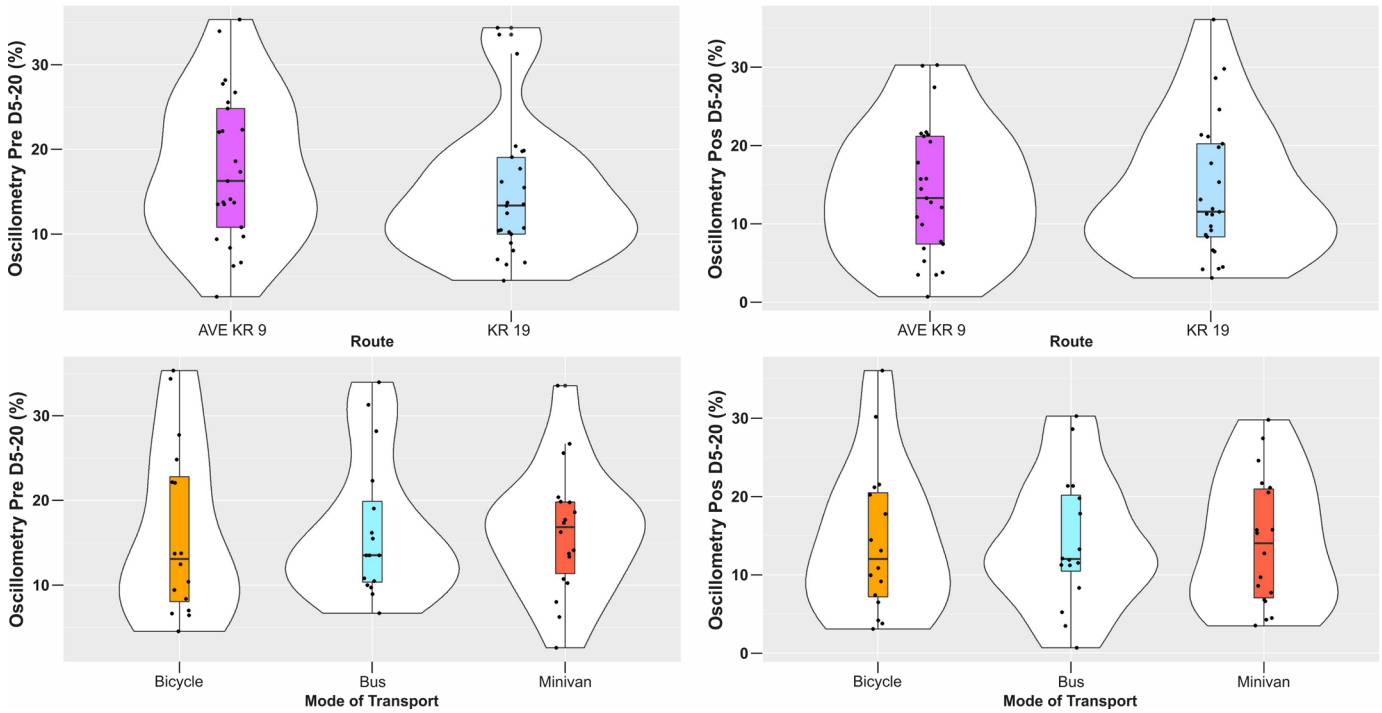

Figure 5. D5-20 pre- and post-travel oscillometry values by route and mode of transportation.

The data presented in the graph reveal notable differences in the $PM_{2.5}$ and eBC concentrations among the different modes of transportation. Specifically, minivan users experienced the highest levels of $PM_{2.5}$ on KR 19, with an average concentration of 19.93 $\mu g/m^3$. On the other hand, buses on KR 19 and bicycles on AV KR 9 exhibited the highest concentrations of eBC, with averages of 6.49 $\mu g/m^3$ and 7.69 $\mu g/m^3$, respectively.

No significant clinical changes were observed in the spirometry parameters when comparing different routes and modes of transportation. The results of the spirometry tests

indicate similar values for FEV1/FVC before and after travel, and these values remained consistent across the various transport modes.

The figure provides a comparison of pre- and post-travel values for two respiratory parameters: FEV1/FVC from spirometry (left panel) and R5 from impulse oscillometry (right panel). In the left panel, the graph displays the pre- and post-travel FEV1/FVC values for both routes. No statistically significant changes were observed in this spirometry parameter, indicating that the lung function remained consistent before and after travel on both routes.

In the right panel, the graph represents the pre- and post-travel changes in the R5 values for each route using impulse oscillometry. It is worth noting that 18% (n = 9) of the participants showed increased peripheral resistance values during the pre-test impulse oscillometry assessment. However, in the post-test measurements, there was an improvement in this parameter, indicating a decrease in peripheral resistance. Importantly, the changes in the R5 values were not found to be associated with the specific route taken ($p > 0.05$), suggesting that the route of travel did not have a significant impact on this respiratory parameter.

The D5-20 values demonstrated similar patterns across genders, with no significant differences observed between the routes in terms of the post-examination responses (mean = 12.27 Hz for KR 19 and 15.63 Hz for AVE KR 9). Importantly, these changes were not associated with the specific route or mode of transportation ($p > 0.05$).

The Wilcoxon test results for pulmonary function parameters did not show any significant differences among the routes and transportation modes, as indicated by the non-significant *p*-values obtained. This suggests that there were no statistically significant changes in the measured pulmonary function parameters across the different routes and modes of transportation.

4. Discussion

In our study, we aimed to assess the impact of short-term exposure to $PM_{2.5}$ and black carbon on lung function in a group of healthy individuals. Our results reveal that the participants who travelled by minivan and bicycles were exposed to higher levels of $PM_{2.5}$ compared to the other modes of transportation. Additionally, minivan users experienced higher concentrations of eBC regardless of the route taken. These heightened pollutant levels can be attributed to factors such as heavy traffic and the presence of cycling infrastructure in these specific areas. These findings are similar to previous results reported in Bogota [19], showing that the levels of pollution experienced by individuals inside diesel buses were significantly higher compared to pedestrians and cyclists [20]. Authors underscored that the remarkably elevated concentrations of the eBC/$PM_{2.5}$ ratio indicate a significant contribution from emissions produced by diesel engines to the presence of fine particulate matter.

We observed no significant changes in the spirometry and impulse oscillometry values associated with air pollutants when analyzing different routes and modes of transportation. These results are consistent with previous reports performed in other sectors of the city which suggest that there is not an association between spirometry changes and exposure to air pollutants in the short term regardless of sex, mode of transportation, or route [11]. Current evidence generally supports a positive link between active transportation and physical activity. Even in cities with moderate air pollution levels, the benefits of physical activity outweigh the potential harm caused by air pollution [21]. However, some authors have suggested that long-term exposure to $PM_{2.5}$ and habitual physical activity may interact negatively [22], indicating that the increased intake of $PM_{2.5}$ during physical activity could diminish the benefits of regular physical activity on lung function [23].

We should underscore that this is the first study using impulse oscillometry to measure the effect of the exposure to $PM_{2.5}$ and black carbon in a sample of health participants. It is worth noting that 18% of the participants showed peripheral airway obstruction patterns in the pre-test oscillometry values. In the post-test, peripheral resistance decreased in

14% (n = 7) of the participants. The impulse oscillometry system has been suggested as a tool to evaluate short-term effects, but in high-risk populations such as children and patients with EPOC and asthma [24]. Studies performed in those populations have indicated that higher concentrations of $PM_{2.5}$ and black carbon are associated with increased differences in central and peripheral airflow resistance [25]. It is important to mention that there is a scarcity of evidence regarding this type of measurement in a healthy adult population [15].

These findings contribute to our understanding of the potential impact of environmental factors on respiratory health. Further research with larger and more diverse samples is needed to strengthen our understanding of the relationship among air pollution, transportation patterns, and respiratory function. Such knowledge can inform targeted interventions to protect and improve the respiratory health of individuals in urban environments.

These findings underscore the significant influence that transportation choices and infrastructure have on air pollutant concentrations. It highlights the importance of implementing targeted interventions to mitigate pollution levels in specific transportation settings [26]. Of particular concern is the prevalence of minivans as a common mode of transportation for children and adolescents in Bogotá. Considering that the duration of exposure during home-to-school trips exceeds that of home-to-office trips in the city, there may be potential long-term effects on the respiratory health of younger individuals.

It is crucial to address these issues and implement measures to minimize the adverse respiratory health impacts associated with high pollutant concentrations. By doing so, we can create healthier environments for individuals, especially vulnerable populations, such as children and adolescents, and ultimately improve public health in urban areas.

This study has several limitations and flaws that should be acknowledged. Firstly, the small sample size used in this study may not be representative of the overall healthy adult population in the city, limiting the generalizability of the findings. Consequently, the study may lack sufficient statistical power to detect significant changes in impulse oscillometry values associated with different routes or modes of transportation.

Secondly, we did not consider night-time exposure to air pollutants, which could potentially affect the pre-travel oscillometry R5 and R20/R5 values. Future studies should account for variations in exposure during different times of the day to obtain a more comprehensive understanding of respiratory function changes.

Thirdly, the assessments of $PM_{2.5}$ and black carbon exposure during the journey were conducted in a minivan. Although efforts were made to minimize external air flow by keeping the windows closed, it was challenging to completely control the exposure to air pollutants. This may introduce some variability in the results and should be taken into account when interpreting the findings.

Furthermore, it is important to acknowledge the limitations associated with the utilization of oscillometry and spirometry techniques in this study. The equations utilized to evaluate these parameters were originally developed using data from non-Latin American populations, and as such, there is a potential for bias in the interpretation of the results. It is crucial to consider the potential variations in respiratory physiology and lung function characteristics among different ethnic and geographical populations, which may impact the accuracy and applicability of these equations in the context of the present study. Further research specifically focusing on Latin American populations is warranted to address these limitations and provide more accurate and context-specific reference values for oscillometry and spirometry measurements.

Lastly, the study design did not include a long-term follow-up. Future research should consider incorporating longitudinal studies to evaluate the impact of air pollution on respiratory health over extended periods of time.

In conclusion, our findings suggest that individuals using minivans and bicycles may experience higher exposure to $PM_{2.5}$ and black carbon. However, we did not observe any significant associations between air pollutant concentrations and short-term changes in spirometry and impulse oscillometry variables. It is important to note that our study had a limited sample size, and further research with larger cohorts is necessary to fully

assess the short-term effects of air pollutant exposure on the respiratory health of healthy individuals. This will contribute to a better understanding of the potential risks and implications associated with air pollution exposure in the general population.

Author Contributions: J.E.A.: Methodology, Investigation, Data Curation, Writing—Original Draft Preparation, Review and Editing, and Visualization; A.R.H.: Review and Editing, Visualization, and Project Administration; A.G.: Investigation, Software Development, Formal Analysis, Data Curation, Writing—Original Draft Preparation, Review and Editing, and Visualization; H.S.: Software Development, Formal Analysis, Investigation, Data Curation, and Writing—Original Draft Preparation; Y.G.T.-P.: Software Development, Formal Analysis, and Data Curation; J.N.M.-R.: Conceptualization, Methodology, Validation, Review and Editing, Supervision, and Project Administration. All authors have read and agreed to the published version of the manuscript.

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

Data Availability Statement: We adhere to the principle of transparency and reproducibility in research. The data supporting the findings of this study are available upon request from the corresponding author. The data are not publicly available due to privacy.

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Conflicts of Interest: The authors declare no conflicts of interest.

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