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Assessment of factors influencing personal exposure to air pollution on main roads in Bogota: a mixed-method study

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Abstract: The Particulate Matter (PM), particles of variable but small diameter could penetrate the respiratory system via inhalation, causing respiratory and/or cardiovascular diseases. This study aims to evaluate the association of environmental particulate matter (PM2.5) and black carbon (BC) with respiratory health and physical activity in users traveling by transportation modes over four roads in Bogotá. This was a mixed-method study, in 300 healthy participants, based on a convergent parallel design. Including a descriptive qualitative component focused on asserting the individual perception of air pollution by semi-structured interviews and a cross-sectional study measuring the individual exposure to PM2.5 and BC to evaluate the pulmonary function by spirometry. The analysis included concurrent triangulation and a Poisson regression. This study provides integration of air pollution exposure variables and respiratory health effects in different transport microenvironments. To our knowledge, this is the first mixed-methods study focused on PM2.5, BC, and respiratory health effects in a city above 2.000 meters above sea level.

Keywords: air pollution; microenvironment; public health; PM2.5; black carbon; active transport.

1. Introduction

The growth of cities has been accompanied by emerging effects such as mobility problems and exposure to environmental pollutants [1,2]. Studies have attempted the complex problem of the promotion of active transportation in cities and risks to human health through exposure to air pollution. Exposure to ultrafine particulate matter in different transport modes has been associated with changes in heart rate [3], cardiovascular, and respiratory pathologies [4–13], especially, in people under 5 and over 65 years old [14,15]. Therefore, cities around the world have promoted walking and cycling or combining such methods with public transportation. This strategy promotes the reduction of emissions and improves air quality while promoting physical activity, particularly in citizens without time or resources to participate in sports or exercise [16–18]. However, urban commuters are a group of concern, given their frequent proximity and repeated exposure to sources of combustion-related air pollutants [19,20]. Studies have estimated that commuting accounted for 30% and 32% of the inhaled dose of daily equivalent BC in Brisbane and Barcelona, respectively. As well as, similar results have been obtained for PM2.5 [21].

In Bogotá, approximately 21,000 deaths and 12,000 hospitalizations of children under five years of age have been attributed to air pollution in the last 10 years old [22]. In 2016, 15,681 deaths were attributable to air pollution [23]. Also, the concentration of

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PM2.5 and BC in different transport microenvironments has been determined up to six times higher in Rapid Transit public transport buses than for pedestrians and bicycle users in the same corridor [24]. However, the sample size and the spatial distribution of the few road segments sampled have limited the scope of those efforts to characterize personal exposure for commuters in Bogotá. In addition, the transport microenvironment is affected by particulate matter depends on other individual variables, such as sex, race, age, body mass index (BMI), lifestyle, usage of a face mask during the trip, history of respiratory diseases, smoking habits, condition of the highway, and presence of green spaces [25]. Moreover, some authors have underscored the role of individual perception, travel attitudes, and travel behavior as determinants of the transport microenvironment [26]. Therefore, qualitative studies could introduce additional elements in the exposure perspective. Sensory perception, such as odor sensations, visually perceived changes in the environment, and skin alterations, may be associated with higher pollution levels since these represent signs and symbols of exposure to polluted air [27].

In the era of active transport [28,29], it is important to evaluate the health risk of promoting physical activity in places where the concentration of PM2.5 is greater than the WHO 2021 standards [30]. Health strategies could reduce the adverse health impact of air pollution. Thus, this study aimed to evaluate the relationship between exposure to particulate matter PM2.5, BC, and the respiratory health of users of modes of transport and routes prioritized in Bogotá, from the perspective of a mixed-method study.

2. Materials and Methods

We performed a mixed-method study with sequential design. Protocols followed were as those in [31] and following the recommendations of the STrengthening the Reporting of OBservational studies in Epidemiology (STROBE) checklist and the statement for observational studies and quality Standards for Reporting Qualitative Research (SRQR) results [32]. The description of the research process is described in Figure 1.

2.1. Study Area

Personal exposure to air pollutants and health variables measurements were performed on four routes urban areas of Bogotá (Figure 2). The routes were chosen based on criteria: i) zones with a wide range of air pollution levels; ii) road with high daily traffic by bicycle, minivan, and regular buses of the Integrated Public Transport System (SITP); iii) non previous monitored research; iv) relevant routes for the Mobility and Environment City Major Bureau (Supplementary materials).

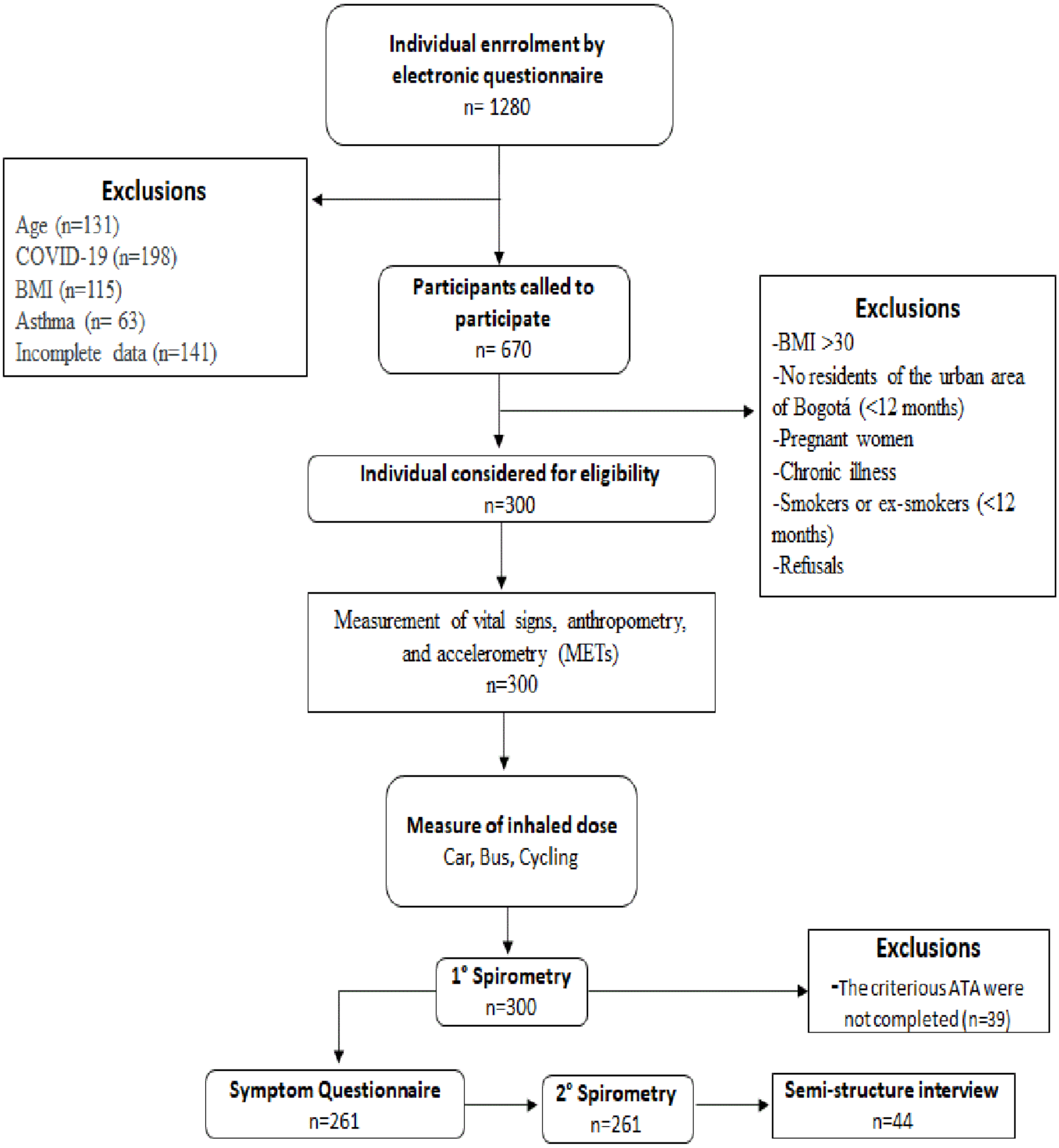

Figure 1. Flow chart description of the research process.

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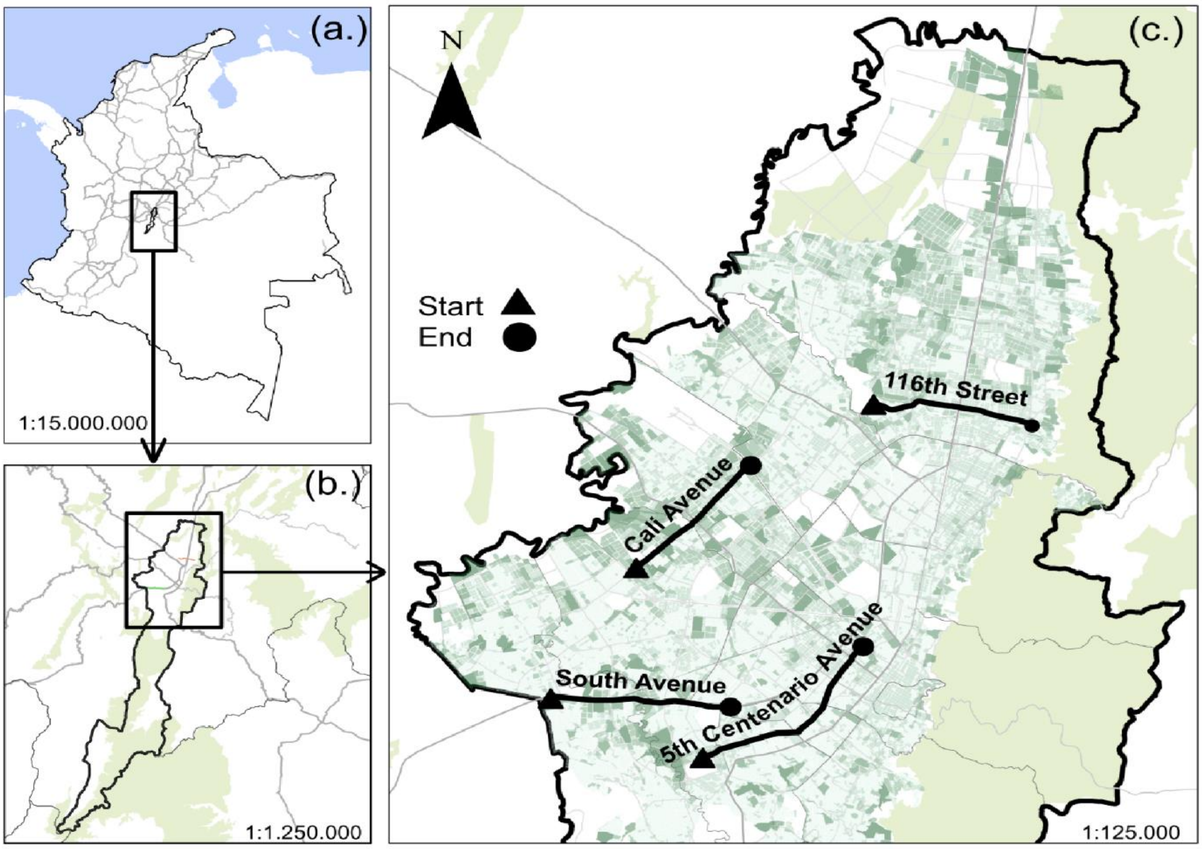

Figure 2. (a.) Geographical location of Colombia and Bogotá. (b.) Spatial location of Bogotá. (c.) Locations of the four monitored routes. Triangles indicate the beginning of the routes, and circles indicate the end.

2.2. Sample and Sampling

The sample included 25.000 participants including workers at governmental agencies or/and students at universities, using a consecutive non-probability sampling, an expected occurrence of the event of 50% ($p = 0.5$), ($q = 1-0.5 = 0.5$), precision of the estimate = ± 6% (δ =0.06), confidence level = 95% ($\alpha = 0.05$, $Z\alpha = 1.96$), and loss percentage = 10%. The minimum sample size was 267 participants.

For the qualitative component, the number of participants was considered by theoretical saturation (defined as the nonappearance during the interviews of new textual elements regarding knowledge, attitudes, and practices related to the perception of air quality) [33].

2.3. Data Collection

An online survey with individual information was completed by each participant between June 2019 and December 2020. Volunteers were scheduled for monitoring on Thursday, Friday, and Sunday from 6 am to 10 am. Measurements were performed from 19th October 2020 to 10th November 2021. The participants were picked up from their home and driven to the initial point of the route in a minivan.

2.3.1. Measurement of anthropometric variables

Anthropometric variables were measured on the day of the monitoring following recommendations from the CDC-Anthropometry Procedures Manual [34]. BMI and artery pressure were calculated according to the recommendations of the WHO [35].

2.3.2. Physical activity

Accelerometry was estimated with an ActiGraph wGT3X-BT accelerometer with three axes using sixty-second epochs and a sampling rate of 30—100 Hz [36]. The ActiGraph was attached to the participant's waist at the beginning of the travel route. For bicycle users, a second accelerometer was attached to the participant's ankle. Data were daily recorded and downloaded using ActiLife®v5, licensed from Instituto Nacional de Salud (INS). We estimated the metabolic equivalent of task (MET) using the Freedson equation and speed [37,38]. For bicycle users, we estimated the mean and median MET between the waist and ankle ActiGraph (Supplementary materials).

2.3.3. Lung function

Spirometry tests and analysis spirometry results were performed by two trained respiratory therapists with a Spirobank G (Medical International Research). Pre-exposure spirometry tests was performed before the trip, and a second spirometry, symptoms questionnaire, and interviews were performed two hours after the journey was completed. Each participant has at least six spirometry tests: three pre-exposure and at least three postexposure. The spirometry tests were recorded using WinspiroPRO Light software (free license).

The best spirometry tests (pre and post) were selected according to the acceptability, repeatability and interpretation criteria of the American Thoracic Society (ATS) and European Respiratory Society [39]. FVC, FEV1, PEF, and forced expiratory flow between 25% and 75% of the FVC (FEF25–75%) were measured. The FVC, FEV1, and PEF values corresponded to the percentage of predicted values computed according to the recommendation for the Hispanic population [40].

The respiratory symptoms survey adapted from the "American Thoracic Society and National Heart & Lung Institute-Division of Lung Disease Respiratory Questionnaire" (ATS-DLD-78-A) was performed. This survey was previously validated for Colombia [41].

2.3.4. Measurements for monitoring personal exposure to PM2.5 and BC

PM2.5 concentrations were measured with a SidePakTM AM520, through a built-in sampling pump [42], and a DustTrak II Aerosol Monitor 8530 [43]. A flow calibration was performed before each use (Supplementary materials). BC was measured using a portable microethalometers MicroAeth AE51 [44]. The AE actively collects ambient air particles in the filter to determine the attenuation of the laser intensity through the filter [45,46]. The data was corrected for filter-loading effects that reduces the instrument sensitivity as the filter loading increases. We applied the correction procedure described previously [47].

Additionally, we included in the analysis the concentration of pollutants of anthropogenic and natural origin, reported by the stations of the Bogotá Air Quality Monitoring Network. From at least two stations surrounding each route. We considered the hourly median, mean and standard deviation for PM2.5 data between 7 am and 11 am on the measurement days.

2.4.5. Semistructured Interviews

A semistructured interview was designed to establish the knowledge, attitudes and practices related to the perception of air quality of participants who commute in a contaminated atmosphere. The social representation theory guided the structuration of the qualitative component. An interview guide was prepared by two of the researchers and validated by three thematic experts (Supplementary materials). (Table 1). Sessions were planned to last 60 min, in Spanish, at the end of the route. The teleconferences were guided as previously published [48].

Table 1. Pre-established categories, definitions, and questions of the semi-structured interview guide.

Category	Meaning	Questions
Knowledge of air quality and health	Mental representations preceding cognitive processes developed, socially constructed, and recreated during everyday interactions.	- What is your perception of the air quality in Bogotá? -What elements in the environment allow you to recognize the air pollution? -Do you know which pollutants affect air quality? -What do you consider to be the sources that impact air quality? -What do you consider to be the mode of transport with the higher exposure to pollutants? -Do you know if air quality has health effects? -What do you consider to be the effects on people's physical, mental, and emotional health and how are they evidenced? -Did you perceive the same air quality on the way? Could you describe it?
Attitudes toward exposure	Means the orientation (positive or negative) before an object of the pre-existing social world. Cognitive, affective, and behavioral components converge in them.	-Does pollution in the city alter your quality of life at all? -What attitude do you assume when exposed to a direct source of pollution? -Do you think you've gotten sick exposure to air quality pollutants? -Have you gotten sick? From what? Are you sick? -Did your attitude change from this episode?
Practices related to exposure	They express both the human experience and all those activities that materialize in a direct and daily relationship of people with the world. They are constituted as an action on reality.	-Do you consider that you take care of yourself and protect yourself against exposure to air pollutants? -Do you know about activities that are carried out in your environment to take care of your health in the face of exposure to air pollutants? Which one? -Of the activities mentioned, do you participate in any of them? -Does your perception of air quality interfere with decisions for your travel or the use of modes of transportation? -How do you think the city's air quality could get better?

2.4. Data analysis

2.4.1. Information Processing and Analysis—Quantitative Data

The participants were interviewed face-to-face. However, eleven interviews were conducted via teleconference due to the COVID-19 pandemic restrictions. We constructed a database using each participant's code as a key and linking sociodemographic, physical activity, spirometry, PM2.5, and BC variables. Data from air pollutants, GPS, and the field registry were synchronized using Wolfram Mathematica® software, V11.0, a license from Universidad de Los Andes (Supplementary materials).

Means, medians, standard deviations, and interquartile ranges were estimated for quantitative variables, and frequencies or percentages for qualitative variables. Pearson's Chi-square test and Yates's correction was used in a bivariate analysis to compare the nominal or ordinal variables regarding sex, transport mode, and route. Spearman correlation was used for quantitative variables. The level of statistical significance was $p<0.05$. Data from measurements of personal exposure to PM2.5 were compared with data from the RMCAB to comprehensively characterize the PM2.5 concentrations.

For associations between sociodemographic factors and spirometry changes a Poisson model was completed [49]. We estimated relative risks (RRs) with 95% confidence intervals. Analyses were performed in R version 4.0.2.

2.4.2. Information Processing and Analysis—Qualitative Data

The analysis of the qualitative data was guided using strategies to ensure credibility [50], trustworthiness using software to ensure traceability of the transcription, coding process [51], transferability (files were stored in MP4 format and on an external hard drive to ensure that all of the phases of analysis could be traced back to original interviews). Once the transcriptions were performed, we returned 14 of them to the participants to obtain feedback [52].

Later, two of the researchers read independently the transcription to have an immersion in the senses of the subjects. Codification was established based on the theoretical elements raised and that refers to the knowledge, attitudes, and practices that the participants have regarding air quality. The coding was conducted by associating textual elements with theoretical constructs, generating a semantic network. The codes and emerged categories were validated by a third researcher. The findings were discussed by three of the coauthors until consensus on categories and subcategories was achieved. Finally, from the selective coding, a description of the content was made to determine the perceptions of the participants regarding the theoretical categories and to determine the relationships between the meanings of the categories. The scope of the analysis was limited to a descriptive level of content. The analysis of qualitative information was performed by ATLAS.ti Scientific Software Development GmbH (License from INS V.8).

2.4.3.Triangulation and integration of results

The study included the integration of data through a triangulation matrix to identify the relationships **[49]**. The analytic triangulation was performed by three of the researchers and a qualitative analysis expert not linked to the project **[50,51]**.

3. Results

3.1. Sociodemographic characteristics

The study included 300 participants. Most of them were female (58.9%, n=148) (Table 2). The average age was 31.61 ± 9.14 years. The average BMI was 23.04±3.34. A total of 300 monitoring trips were completed, most of the trips were conducted in a bus (37.7%; n=113), followed by minivan (35.3%; n=106), and bicycle (27%; n=81).

Participants most used private vehicles (41%) and buses (35.5%). Considering the transport mode, no relevant differences in age (Chi2=84.47; p=0.149) or BMI (Chi2= 357; p= 0.532) were observed. Bicycle users were mostly men (54%). The participants were formal workers (50%) and students (17.5%), university degree (62%), knew how to ride a bicycle (90%), declared a good quality of life (96%) and satisfied with their health (90%).

Table 2. Sociodemographic characteristics and spirometry parameters.

Variable		Minivan	Bicycle	Bus
Age (years) (mean ± SD)		32.84 ± 10.35	31.75 ± 8.35	30.86 ± 8.78
BMI (mean ± SD)		22.94 ± 3.46	22.95 ± 3.21	23.22 ± 3.36
Sex	Male % (n)	28.3% (n=30)	59.26% (n=48)	38.05% (n=43)
	Female	71.7% (n=76)	40.74% (n=33)	61.95% (n=70)
Routes	Cali Avenue	23.58% (n=25)	25.93% (n=21)	25.66% (n=29)
	116th Street	26.42% (n=28)	25.93% (n=21)	23.89% (n=27)
	South Avenue	25.47% (n=27)	22.22% (n=18)	25.66% (n=29)
	Quinto Centenario Avenue	24.53% (n=26)	25.93% (n=21)	24.78% (n=28)
Spirometry parameters (mean ± SD)	Pre-FVC	3.79 ± 3.79	4.34 ± 4.34	3.87 ± 3.87
	Post-FVC	3.72 ± 0.76	4.26 ± 0.86	3.88 ± 1.14
	Pre-FEV1	3.08 ± 0.66	3.55 ± 0.68	3.21 ± 0.88
	Post- FEV1	3.14 ± 0.62	3.53 ± 0.69	3.25 ± 0.85
	Pre-FEF25-75%	3.48 ± 0.93	3.69 ± 1.02	3.47 ± 1.13
	Post-FEF25-75%	3.58 ± 0.94	3.68 ± 1.02	3.63 ± 1.05
	Pre-FEV1/FVC	82.86 ± 8.20	82.20 ± 5.70	83.40 ± 6.26
	Post-FEV1/FVC	83.88 ± 9.47	82.92 ± 5.27	83.54 ± 9.82

The number of monitoring trips was similar for each of the selected routes: 116th Street (25.33%; n= 76); Southern Highway (24.7%; n=74), Cali Avenue (25%; n=75), and Quinto Centenario Avenue (25%; n=75). The average duration of the route in minutes was 27.27 ± 9.4 for 116th Street, 29.37 ± 12.5 for Southern Highway, 31.4 ± 13.3 for Cali Avenue and 41.4 ± 16.5 for Quinto Centenario Avenue (Supplementary materials).

3.1. Air quality perception

Participants declared that the quality of the air they breathed was regular (47%); poor (24%), and very poor (12%). Also, the link between air quality and health (72%). According to the perception of the participants, the systems most frequently affected by air pollution were respiratory (94%), visual (72%), skin (67%), cardiovascular (41%), and gastrointestinal (17%). Air pollution was identified as the air became dark (75%) or white (22%). They recognized the smell of the air pollution (72%). Protection against air pollution was used (62%); the most frequent protective element was a surgical/fabric face (40%) and N95 mask (7%). The participants mentioned practices such as closing windows (16%), opening windows (7%), and holding their breath (10%) during travel.

3.2. Spirometry parameters

Spirometry tests were performed on 300 participants. However, 13% (n=39) of the spirometry tests were excluded because the criteria of the ATS were not fulfilled. All participants presented normal pre-and post-trip spirometry results, alterations in lung volume were not evidenced. Change between the FEF25-75% pre- and post-trip spirometry volumes in women ($p=0.04$) but not in men ($p=0.12$) was found. The FE/FVC pre-and post-trip spirometry results showed a significant difference ($p=0.03$). This difference was more noticeable among women ($p=0.02$), but it was also relevant among men ($p=0.04$). However, these changes were not noticeable when the results were stratified by route or mode of transport ($p>0.05$) (Supplementary materials).

3.3. Respiratory symptoms

All the participants completed a survey of symptoms at the end of each trip. The most frequently reported symptoms were nasal airway obstruction (29%), nostril discomfort (23%), conjunctival hyperemia (17%), and runny nose (12%).

3.4. Physical activity

The average MET was higher among bicycle users. The higher MET among bicycle users was significant (Chi2= 106; $p=0.008$) (Supplementary materials).

3.5. Personal Exposure

Non-normal distributions were observed for all modes and routes. Logarithm-scale plots were made to visualize the behavior of the data more easily. The PM2.5 concentration was greatest in buses (median 50.67 μg m-3; IR: 306.7), followed by minivans (median 38.49 μg m-3; IR: 182.3), and bicycles (median 23.39 μg m-3; IR: 50.23). The differences were statistically significant ($p<0.05$). Similarly, BC concentrations were the highest in buses (median 29.94 μg m-3; IR: 116.3) and differed significantly from concentrations in bicycles (7.83 μg m-3; IR: 26.6) and the minivan (18.54 μg m-3; IR: 68.6). The differences were statistically significant ($p<0.05$) (Supplementary materials). The concentration of PM2.5 was significantly lower ($p<0.001$) at 116th Street (median 15.66 μg m-3; IR: 59) than at the Southern Highway (median 60.18 μg m-3; IR: 202.7) and Cali Avenue (median 54.64 μg m-3; IR: 304.4). Similarly, the BC concentrations were greater at the Southern Highway (median 23.58 μg m-3; IR: 113.8) and Cali Avenue (median 22.21 μg m-3; IR: 102.8) than at 116th Street (median 6.37 μg m-3; IR: 30.9) (Supplementary materials). The concentrations of PM2.5 and BC were significantly lower on all routes and modes on Sundays than on weekdays ($p<0.001$).

The background concentrations of PM2.5 reported by the RMCAB were greater at the Southern Highway and Cali Avenue. As expected, the PM2.5 concentrations were two or more times greater in the personal exposure measurements than those registered by the RMCAB (Supplementary materials).

3.6. Inhaled dose

The average inhaled dose of PM2.5 was 11.50 μg ± 13.68, while the average inhaled dose of BC was 17.95 μg ± 23.36 8 (Supplementary materials). The inhaled doses of PM2.5 and BC were significantly higher among men than among women ($p<0.0001$). Also, the participants on bicycles experienced higher inhaled doses, followed by the participants on buses (Supplementary materials). Nevertheless, there was no association between inhaled doses of PM2.5 and BC and route or transport mode ($p>0.05$). Also, there was no correlation between the spirometry parameters, age, body mass index and inhaled doses of PM2.5 and BC ($p>0.05$). There was a positive correlation between the time of the commute and the inhaled doses of PM2.5 (Spearman 0.53; p= 3.6504E-21), and BC (Spearman 0.46; p= 1.3962E-16).

3.7. Multivariate model

No risk factors were associated with changes in FVC, VCF1, or FCV/ VCF1. The participants in Quinto Centenario route had a post-trip FEF25-75% volume 2.48 times lower than that of participants on the 116th Street route. Nevertheless, the changes in FEF25-75% were not clinically relevant (Table 3).

Table 3. Multivariate model Post FEF25-75%

Route	**RR***	**CI 95%**		***P***
Southern Highway	1.011	0.493	2.072	0.977
Cali Avenue	1.692	0.827	3.461	0.150
V Centenario Avenue	2.486	1.165	5.306	0.019
116 Street	1			
Mode				
Minivan	1.214	0.658	2.240	0.534
Bike	0.862	0.459	1.618	0.644
Bus	1			
Inhaled $PM_{2.5}$ dose	0.978	0.956	1.000	0.360

*RR from Poisson regression model showing that the participants who made the journey by V Centenario avenue had 2.4 times the risk of having a reduction in the FEF25-75% compared with 116th street.

3.8. Semi-Structured Interviews

A total of forty-four semi structured interviews were conducted. Among the interviewees, 59% were women, 55% were between 18 and 26 years old, 43% traveled by private vehicle, 32% by bicycle, and 25% by public transportation. Categories and subcategories are presented in the supplementary materials. The knowledge was represented by the identification of contamination levels and the effects on health and quality of life (Supplementary materials). Air pollution levels were generally perceived as poor, participants, regardless of their transport mode, the route on which they traveled, or their sex, acknowledged, being exposed to high levels of contamination. This perception was mediated by the sensory influence, with the visual and olfactory perception being the two main referents of changes in environmental conditions. Thus, the smell of smoke and the visibility of smog were significant sensory evidence that the interviewees perceived when traveling through different areas of the city. Although,

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many of the interviewees referred to this sensory perception generated by the exposure, the bicycle users recognized changes in these sensory experiences with greater intensity.

P 8: MALE CENT BICI–8:2 The pollution is awful, and, well, in the quality of the air that one breathes... you perceive it in the smell. One says, not here, it smells terrible. Even if you are not seeing the smoke that is coming out of the car, you feel it...

Public, cargo, and private transportation, as well as industries, were recognized as the main sources of air pollution.

P 6: MALE 116 VAN–6:6 The issue of mobile sources, especially public service, and cargo transportation, is what most influences [air quality], and I would say that the second activity would be industrial activities in some sectorized areas of the city.

We observed a link between the presence of symptoms and levels of exposure with both short- and long-term effects. Long-term health effects, linking exposure to the onset of chronic respiratory diseases and even lung cancer.

P26: MALE AUTOSUR BUS–26:9 Allergies and discomforts such as eye and skin irritation, as in the short term some cancer, a disease in the background is long term because it results from being exposed for a long time.

Participants underscored a relationship between air pollution and mental health. The perception of air quality arouses affective and emotional states reflected in changes in mood, such as feelings of anger, helplessness, irritation, and stress, which can lead to alterations in the mental health of the participants.

P 7: FEMALE CENT BICI–7:24 Clearly, between the perception of air quality, or between the perception of pollutants and emotional processes, there is something very, very strong, and that is that we read the world through what we perceive, and we are going to do that through our senses. Then, I do believe that there is a close relationship, I think that this fosters a lot of the mental health problems that we have today. I think that it also makes people prone to violence because it also becomes a violent, hostile context.

3.9. Attitudes toward exposure

Attitudes of changing to avoid the risk were identified (Supplementary materials). One group was established by participants who had more empirical notions about how to protect themselves from air pollution and that showed more active attitudes toward the risk and assumed responsibility for their protection.

Active attitudes implied the use of elements to cover the nose and mouth in the face of direct exposure and the realization that physical activity reduces the risk of diseases. Additionally, changing attitudes implied modifying the routes used to travel from home to work. These attitudes were more frequently manifested by bicycle users, who showed a greater capability of influencing their exposure than minivan or bus users.

P20: FEMALE CALI VAN–20:8 When I see a car that is smoking too much, I always try to cover myself, not to inhale; that's like my attitude.… It's about self-protection.

A second group was established by participants with minor empirical knowledge about air pollution and risk. This group showed more passive behaviors, such as accepting the situation because it was not possible to influence the air pollution conditions. Attitudes of resignation were expressed, and naturalization was recognized as poor air quality and related to health risks. The participants' attitudes suggested that being exposed was an unavoidable condition without a solution.

P25: FEM AUTO SUR BUS–25:10 It is difficult because what I tell you, it is like getting used to living in this atmosphere, like all the time for me it is normal.

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3.10. Practices toward exposure

We identified two main practices associated with air pollution exposure: individual practices (protection and reduction) and collective practices (Policies and regulations, land use planning, information management) (Supplementary materials). The first individual practice was the usage of personal protective equipment such as face masks or scarves. Related practices were rolling up/down windows, covering the mouth and nose, and holding the breath.

The second individual practice was the use of alternative modes of transport. The usage of bicycles for commuting is associated with a reduction in emissions and with a positive impact on individual health.

Collective practices were linked to "political actions" toward promoting health and environmental rights. It was widely recognized that there are not enough state actions to guarantee air quality in the city, but the participants also felt that there were not sufficient legal elements to allow them to participate in political decision-making related to air pollution. The participants expressed their impotence to influence political action related to air pollution and expressed a feeling of abandonment associated with the absence of a strong state that could protect citizens from private interests that can bend legislation on air pollution and sources of exposure.

P 8: MALE CENT BICI–8:14 …The muscle of the entities is deficient... Colombia is full of standards, at an environmental level, there are many standards, but the muscle to enforce those standards, the legal and economic muscle of the companies, can be more than the standard. So, if that does not change in this society (which is another of the things that bother me at a social level), substantial changes will not be seen

4. Discussion

A mixed sequential explanatory study was conducted to evaluate the relationship between exposure to particulate matter PM2.5, BC, and the respiratory health of users who commute by minivan, public transportation, and bicycle on prioritized routes in Bogotá. To our knowledge, this is the first study conducted in this population that focuses on understanding the relationship between exposure to air pollutants, individual perceptions, and health outcomes. Studies in this area are mostly of a quantitative or qualitative nature, but mixed-method designs are uncommon.

The results were consolidated in the triangulation matrix shown in Supplementary materials. A vast majority of the participants rated the air quality in the city as not good enough. The qualitative data extracted from the interviews tallied with the quantitative information, and both the quantitative and qualitative data sets agreed that there was a link between health and air quality. Air pollution was frequently associated with the presence of respiratory and visual discomfort. But also, with symptoms such as anxiety, stress, and irritation. These findings were like those previously reported by Buoli & Cols (2018), where the authors found that prolonged exposure to PM2.5 was associated with an increased risk of depressive symptoms [52]. Additionally, higher life satisfaction, more self-esteem and higher stress resilience are predicted by less air pollution (PM10) was observed in a Ger-

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man study [53]. In addition, standard deviation increase in particulate matter over an average PM2.5 concentration, increases the likelihood of mental illness, including depression [54].

Of the participants, 62% used some type of equipment to protect themselves from air pollution and this practice was more frequent among the bicycle users. These findings were in line with the individual practices declared in the interviews. The usage of face masks and practices such as closing windows to reduce the health consequences of air pollution has been reported [54]. Wearing a face mask appeared to effectively reduce symptoms and improve cardiovascular health measures in patients with coronary disease [55]. Also, masks contribute to reducing the adverse effects of air pollution on blood pressure, even among healthy volunteers [56]. In addition, air pollution levels seemingly affect people's behavior, reducing the practice of physical activity outdoors [57]. As air quality worsens, people tend to decrease their walking and cycling and to travel more by bus or subway [58].

Considering the levels of activity, we found that bicycle users had higher MET levels, followed by bus participants. These results are like other previously reported [59].

There were no pathological changes in the spirometry, not even between sex, mode, or route. Several studies have found positive associations between physical activity and lung function levels in adults [60–62]. Most current evidence suggests that there is a positive association between active transport and physical activity. Even in cities with moderate air pollution levels, the benefits of physical activity outweigh the harm caused by air pollution [63]. Nevertheless, some authors have proposed that significant negative interaction effects exist between long-term exposure to PM2.5 and habitual physical activity, suggesting that the increased intake of PM2.5 due to physical activity may attenuate the benefits of habitual physical activity for lung function [64]. Although spirometry is the most common and practical test to measure lung function, it should be noted that it may fail to evaluate acute injury or inflammation from short-term exposure to contaminants.

The concentration of PM2.5 was highest in buses, followed by the minivan and bicycles. Similarly, the concentrations of BC were the highest in buses, and they differed significantly from the concentrations in bicycles and minivans. Our findings differ from the findings from Chaney et al. The authors studied the exposure to PM2.5 in different European cities. They found that the exposure rates were highest for cycling (18.0 μg/hr) and walking (16.8 μg/hr) and lowest for driving with windows closed (3.7 μg/hr) [65]. The differences in the results may be explained by many factors. Traffic volume and diffusions conditions for the air pollutants may affect the exposure levels [66]. In our study the bike line was located on the pedestrian path in most of the measured tracks, which could reduce the exposure to PM2.5. Despite there were not significant differences in the time of the journeys for each transport mode, bus and minivan users may last more time motionless due to traffic jams or waiting in the bus station, while bike users are more likely to be in movement. Even when they may be more exposed to traffic exhausts, the exposure time may be minor compared to the time in the motorized modes.

Participants on bicycles showed greater PM2.5 and BC inhaled doses, followed by the participants on buses. Similarly, Peng reported that PM2.5 active commuters were exposed to higher inhaled doses whereas car drivers inhaled the lowest doses [67]. Driving with closed windows and air conditioning contributed to reducing the PM2.5 concentrations in minivans by 22% [67].

Association between inhaled PM2.5 dose were not found, or in BC dose, and route or mode of transport (p>0.05). A comparative study that focused on comparing air pollution exposures in active vs. passive travel modes in European cities found that the estimated inhaled doses were greater for active modes (6.83 μg for walking and 2.78 μg for cycling) than for nonactive modes (1.28 μg for light-rail trains, 1.24 μg for driving with the windows open, 1.23 μg for buses and 0.32 μg for driving with the windows closed). Bicycle users had higher rates of inhaled dose than commuters using automobiles or public transportation [68].

Despite these inhaled doses in active transport users, there was no correlation between the spirometry parameters, age, body mass index, and inhaled doses of PM2.5 and BC (p>0.05). This may be explained by many factors. First, all the users wear a surgical facemask. Many authors have shown that N95 and disposable facemask may reduce the number of particles to less than 2.5 microns, able to reach the alveoli [69]. Second, the physiological adjustment for individuals living at high altitude (2,600 m.a.s.l.) [70]. Considering that we only included participants who have lived in Bogota for at least the last twelve months, the respiratory frequency of the individuals in the study is adapted to the high-altitude conditions, showing lower inhaled doses of air pollutants, even among bike users.

Also, spirometry may not be sensitive enough to identify changes in lung volumes due to acute exposure to PM2.5 [71]. Some authors have proposed that FEV1 and FEF25-75% flow are affected by short-time exposure to PM2.5, even in healthy participants [72–74]. It should be considered that the median exposure concentrations in our study did not overlap the WHO threshold for diary PM2.5 exposure. In this sense, the combination of facemask usage, physiological adaptation to altitude and sensitivity of the spirometry may explain the absence of associations between concentrations of particulate matter, BC, and respiratory outcomes.

Regarding the limitations of the study, the results are restricted to the modes, routes, and participants in the study. First, it is not possible to extrapolate the conclusion to other groups, even other residents of the city, due to the nature and scope of cross-sectional studies. Second, despite trying to ensure a sample of healthy volunteers, we were unable to ensure that the participants had not been exposed to tobacco fumes or other pollutants the day before the measurements. Third, spirometry is not an easy test and may be affected by the participant. The repeated forced expiratory maneuvers may have annoyed the volunteers and reduced the quality of the obtained curves. Changes in the spirometry results may be associated with the nature of the exercise. We tried to control this potential bias by performing the second set of spirometry tests two hours after the tour ended. Fourth, accelerometry may underestimate MET inactive modes such as bicycling. We tried to control

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this potential bias by using an average between the MET obtained from the accelerometer on the hip and the ankle in the case of bicycle users. Fifth, although we tried to control exposure to air pollutants during the journey from home to the starting location, we could not ensure that exposure to PM2.5 and BC were equal to zero. Therefore, spirometry results could have been affected by exposure in the vehicle transporting the participants to the starting point. Sixth, exposure to PM2.5 and BC was measured with the SidePakTM AM520, the DustTrak II Aerosol Monitor 8530, and portable microethalometers. A comparative analysis using gravimetric methods of sampling was not performed. To reduce the risk of bias in the PM2.5 and BC measurements, we used a protocol to calibrate the monitors to ensure the quality of the collected data. Seventh, since the study was performed on healthy participants, we were unable to ensure that the concentrations of PM2.5 and BC were "safe" enough to promote physical activity among high-risk populations (pregnant women, elderly individuals, and children under the age of five). Eighth, the analysis of the transcripts from the semistructured interviews was conducted by only one researcher, and only two coauthors validated the codes and categories obtained from the transcriptions. We tried to reduce this bias by the peer debriefing process. Finally, it was not possible to include the model or technology of the buses in the analysis. It may contribute to explaining better the differences in PM2.5 and BC concentrations among different routes.

5. Conclusions

The study shows relevant data for personal exposure in different transport modes through four main routes in Bogotá. Even, pathological changes in the spirometry parameters were not observed, the estimated concentration of PM2.5 and BC may have adverse health effects in the long term.

People's perceptions are a preponderant element in the assessment of air quality, and it is suggested that environmental policy incorporates this type of information into its strategies. Incorporating individual and collective perception into actions implies optimizing information transfer and access processes in a way that promotes social learning and empowerment and therefore promoting the transformation of health and action through health prevention.

This information is relevant since it can make citizens aware of the importance of air quality and therefore not only promote sustainable modes of transport but also stimulate participation for the incidence in planning instruments, especially when participants are acknowledged of being exposed to high levels of contamination and are receptive to take part in political action.

Supplementary Materials: The following supporting information can be downloaded at: www.mdpi.com/xxx/s1, Figure S1-6: title; Table S1-S5; Initialization manual, download and transformation of accelerometer data; guide for upload, download and sync aethalometer and sidepack data; guideline for semi-structured interview; STROBE Statement—checklist and Consolidated criteria for reporting qualitative research (COREQ): a 32-item checklist

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

Data Availability Statement: In this section, please provide details regarding where data supporting reported results can be found, including links to publicly archived datasets analyzed or generated during the study. Please refer to suggested Data Availability Statements in section "MDPI Research Data Policies" at https://www.mdpi.com/ethics. If the study did not report any data, you might add "Not applicable" here.

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