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Ultrafine particles and black carbon personal exposures in asthmatic and non-asthmatic children at school-age

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ABSTRACT

Traffic-related air pollution (TRAP) exposure during childhood is associated with asthma; however, the contribution of the different TRAP pollutants in each microenvironment (home, school, transportation, others) in asthmatic and non-asthmatic children is unknown. Daily (24 h) personal black carbon (BC), ultrafine particles (UFP), and alveolar lung deposited surface area (LDSA) individual exposure measurements were obtained from 100 children (29 past and 21 current asthmatics, 50 non-asthmatics) aged 9±0.7 years from the INMA-Sabadell cohort (Catalonia, Spain). Time spent in each microenvironment was derived by the geolocation provided by the smartphone and a new spatiotemporal map-matching algorithm. Asthmatics and non-asthmatics spent the same amount of time at home (60% and 61%, respectively), at school (20%, 23%), on transportation (8%, 7%), and in other microenvironments (7%, 5%). The highest concentrations of all TRAPs were attributed to transportation. No differences in TRAP concentrations were found overall or by type of microenvironment between asthmatics and non-asthmatics, nor when considering past and current asthmatics, separately. In conclusion, asthmatic and non-asthmatic children had a similar time activity pattern and similar average exposures to BC, UFP and LDSA concentrations. This suggests that interventions should be tailored to general population, rather than to subgroups defined by disease.

KEY WORDS: Asthma, ultrafine particles, black carbon, personal monitoring, microenvironments, children.

PRACTICAL IMPLICATIONS

Asthmatic and non-asthmatic children had similar time activity patterns and personal exposures to traffic air pollutants. This suggests that interventions should be tailored to general population, rather than to subgroups defined by disease.

1. INTRODUCTION

Childhood asthma is the most common chronic disease in children, and the prevalence varies from 5 to 10%[1]. Traffic-related air pollution (TRAP) exposure during childhood has been associated with increased incidence of childhood asthma[2] and increased risk of asthma exacerbations[3-5]. TRAP is a complex mixture of particulate matter and primary gaseous emissions and it is still unknown which of these components contribute mostly to the development of childhood asthma[6]. Black carbon (BC) is considered a good indicator of harmful particulate substances emitted by combustion sources, such as TRAP, better than $PM_{2.5}$ and PM_{10}[7] and, therefore, it is appropriate for developing traffic-related policy measures[8-9]. BC exposure has been associated with increased risk of incidence and prevalence of asthma during the first 6 years of life[2,10]. Ultrafine particle number (UFP, < 100 nm) are of special concern since they have a greater surface area and alveolar deposition fraction than $PM_{2.5}$ and PM_{10}, the potential to translocate from the lung into the blood stream and into other organ system, and the ability to induce inflammation and oxidative stress[5,11,12]. Since the particle surface area appears to be associated with higher toxicity of atmospheric UFP[13-14], lung deposited surface area (LDSA) could help to understand differences on health outcomes from the same amount of particle mass[15]. Exposure to UFP has been associated with decreased lung function and increased lung inflammation among asthmatic adults[16-18]. Studies in children suggest that UFP are associated with increased incidence of asthma but the literature remains inconclusive[13].

Land use regression (LUR) has been the most used technique to estimate medium and long term TRAP exposure during childhood[20-21]. However, TRAP can be better estimated by using personal monitoring which allows an accurate measurement of the actual particle concentration levels that

children are exposed to in relation to each microenvironments (home, school, transportation and others) visited[22-24]. This is particularly important for UFP with a high spatial variation[5,25]. Moreover, the relative contribution of TRAP pollutants in indoor microenvironments (e.g. home and school) is still understudied[6]. Few studies have characterized personal BC and UFP exposure in children with enough temporal resolution to assess the contribution of every microenvironment visited, revealing the importance of transport and cooking activities for BC and UFP, respectively[26-29]. Nonetheless, none of these studies measured personal BC and UFP exposure in asthmatic children which represents one of the most vulnerable groups to TRAP exposure. Only two studies, both conducted in US, have assessed 24 h personal exposure to elemental carbon (EC), which is highly correlated with BC[30], in asthmatic children and observed that personal EC was associated with increased risk of wheeze and decreased lung function[23,31]. However, none of these studies included a control group of non-asthmatic children or used temporal series resolution of EC exposure; therefore, without providing insights of the contribution of the different microenvironments on TRAP concentration. In this study we aimed to compare activity patterns and average exposure concentrations in each microenvironment to BC, UFP and LDSA between non-asthmatic and asthmatic children. Our hypothesis is that the disease is changing both the timing and the average exposure concentrations by changing behaviors to avoid air pollution exposures.

2. METHODS

2.1. Study population

A population-based birth cohort was established in the city of Sabadell (Catalonia, Spain) as part of the INMA (INfancia y Medio Ambiente - Environment and Childhood) Project[32]. A total of 657 pregnant women were recruited in the primary health care centre between 2004 and 2007 in the first trimester of pregnancy. All of them fulfilled the inclusion criteria: age of 16 years or greater, intention to deliver in the reference hospital, singleton pregnancy, no assisted conception, and no problems with communication. Additionally, 130 extra pregnant women, with the same

characteristics, were recruited between May and July 2007 at the moment of delivery. All the 787 children were examined at birth, 6 months, 1.5, 4, 7, and 9 years of age. Informed consent was signed and the study was approved by the ethics committee of the Institut Municipal d'Investigació Mèdica (IMIM), Barcelona, Spain.

Parents answered a questionnaire adapted from the International Study of Asthma and Allergies in Childhood (ISAAC) guidelines[33] at 6 months, 1.5, 4, 7 and 9 years of the child. We classified a child as asthmatic if the parent replied yes at least in two of the questions asked at 4 or 7 years in relation to the last 12 months on wheezing or whisteling, ever suffered with asthma, taken any medicines for wheezing/whistling, ever been diagnosed by a doctor as having asthma, or taken any medicines for asthma/breathing difficulties. Within asthmatics we classified past vs. current asthma cases. We classified an asthma case as current if they replied yes at least in two of the questions asked at 9 years in relation to the last 12 months on wheezing or whisteling, ever suffered with asthma, taken any medicines for wheezing/whistling, ever been diagnosed by a doctor as having asthma, or taken any medicines for asthma/breathing difficulties. If not we classified the asthma case as past.

We classified a child as non-asthmatic if parents replied never to the question asked at 6 months and 1.5 years on how often had the child "whistled" in the last 6 months and no to the question asked at 4 and 7 years on wheezing in the chest. Based on this classification, we selected 50 asthmatic (29 past and 21 current) and 50 non-asthmatic children at the age of 9 years (standard deviation (SD): 0.7) of the 787 mother-child pairs initially enrolled. We selected children at random within the asthmatics and non-asthmatics of the cohort.

2.2. Personal Exposure Monitoring (PEM)

The experimental campaign, designed as part of the HELIX and EXPOSOMICS projects[34-35], was carried out in Sabadell (Catalonia, Spain), a city of nearly 200,000 inhabitants situated in the metropolitan area of Barcelona, on school days from January 2014 to June 2015. The PEM

equipment was composed of a MicroAeth model AE51 (AethLabs; San Francisco, USA), a DiSCmini (Matter-aerosol; Wohlen, Switzerland) and a smartphone model Samsung Galaxy Young (Samsung; Seoul, Korea) running the ExpoApp application (Ateknea Solutions; Barcelona, Spain). The MicroAeth and the DiSCmini were located inside a backpack, with the inlet in the breathing zone, whereas the Smartphone was located in an elastic belt in the front side of child's waist. Each child carried the PEM equipment to all the microenvironments where he/she went during 24 h. During the time that it was not possible to carry the backpack, children were instructed to keep the backpack in close proximity to them and at least at 1.5 m above the floor. We also asked them to write down when they started and finished those activities and the type of activity (e.g. showering and swimming). They were also instructed to charge the PEM equipment approximately every 6 h during class time and at night. All devices were synchronized at the start of each monitoring period.

The BC and UFP exposures were obtained, as time-series datasets, in one minute resolution from the MicroAeth[36] and in one second resolution from the DiSCmini[37]. All MicroAeths and DiSCminis were calibrated during the year before the experimental campaign. The MicroAeth is an instrument based on Aethalometer technology, which measures BC air concentrations by using light emitting diodes at 880 nm. The BC dataset was post-processed by using the optimized noise-reduction averaging (ONA) algorithm[38], which reduces the occurrence of negative values to virtually zero while preserving the significant dynamic trends in the time series. The MicroAeth flow was set at 100 ml/min and was checked every week and calibrated if it exceeded the range 100 ± 2 ml/min. A new filter strip was used for each participant. The DiSCmini is a diffusion size classifier capable to detect UFP and it is based on unipolar charging of the aerosol, followed by detection in two electrometer stages[37]. The LDSA concentration is the particle surface area concentration per unit volume of air, weighted by the deposition probability in the lung[37]. For particles smaller than ~0.3 µm, a good correlation has been found between LDSA and the signal of a diffusion charger (TSI model 3550 NSAM) both for the alveolar and tracheobronchial parts of the lung[39]. We processed the DiSCmini data with a Java tool provided by the manufacturer (http://fierz.ch/minidisc/), to obtain

the UFP and alveolar LDSA dataset. UFP dataset was post-processed with an algorithm which removed the data recorded with a DiSCmini malfunction, negative or zero values, and values with a difference of more than 10% with the previous value.

The geolocation data of each participant was obtained from ExpoApp[40] in a one second resolution time-series dataset. We considered that a child's daily overall exposure to TRAP is mainly determined by particle concentration levels at home, school and transportation[41]. Therefore, we assigned each geographical coordinate provided by ExpoApp to one of the following microenvironments: home, school, transportation or others by using a newly developed spatiotemporal map-matching algorithm[42]. We also calculated the overall exposure which includes the four microenvironments. In brief, the algorithm classifies the points as clustered or not clustered (places or transportation) by using the circular variance of the azimuths of groups of time sequential points. This algorithm is not able to distinguish between different transports modes. Based on the clusters spotted by this process, the algorithm selects others points under a defined space and time threshold (20 m and 1 h) and considers them as part of the same spatiotemporal cluster, splitting between spatial clusters when there is a distance equal or larger than 50 m. The algorithm then calculates the centroid of each spatial cluster, using the geocoded points provided by the mother of the child, to identify home and school places[42].

Missing data occurred due to participants not complying with the PEM equipment charging instructions or devices failures. The presented total daily analysis is based on children who had at least 23.5 h (out of 24 h) of PEM data available for MicroAeth and DiSCmini independently. For the home microenvironment, we included those children with at least 85% of the night time (23:00 - 07:00) exposure data available. For the remaining microenvironments we included those subjects with a minimum of 1410 min of smartphone data and 85% of the exposure data for the corresponding microenvironment available.

2.3. Other covariates

Information on parental educational level was obtained from face-to-face interviews to the mothers during the first trimester of pregnancy. Information on gas cooking, home and school geolocalization (address provided by the mother in a Quantum GIS map 1.8.0-Lisbon; OpenLayer pluguin 1.1.0) and whether the parents or others smoked at home was obtained from face-to-face interviews to the mothers during personal monitoring at 9 years of the child. Information on sex, birth weight, and date of birth was obtained from clinical records. Weight and height of the child was measured at 9 years and body mass index (BMI) was calculated.

2.4. Statistical analysis

Bivariate analyses (Mann Whitney test, Kruskal-wallis, Chi squared or Fisher Exact tests) were used to evaluate potential differences in children characteristics between asthmatics and non-asthmatics. Bivariate analyses were also used to explore the differences in time-activity patterns between asthmatics and non-asthmatics. Linear regression models were used to evaluate associations between children characteristics and log-transformed exposure concentrations (BC, UFP and LDSA). Finally, bivariate analyses were used to evaluate differences in exposure concentrations in each microenvironment between asthmatics and non-asthmatics. In case there were differences in pollution levels by asthma, we conducted multivariate linear regression including children characteristics in the model. Pearson correlation coefficients were calculated between personal exposures concentrations of BC and UFP for each of the microenvironments. All statistical analyses (data management and descriptive statistics) were performed using R, v 3.2.3.

3. RESULTS

Table 1 presents the main characteristics of the study population (50 asthmatics and 50 non-asthmatics). Asthmatic (all and past/current) and non-asthmatic groups differed by age, height, and season when PEM was performed. We observed no differences among groups in terms of sex, BMI, parental educational level, mother smoking at home, and gas cooking.

Figure 1 shows the daily time-activity patterns for the study population split by asthmatics and non-asthmatics, based on the smartphone geolocation data of each child. On average, asthmatics and non-asthmatics spent 60.1% (57.2 – 63.0) and 61.3% (56.9 - 63.8) of the time at home; 20.4% (19.3 - 22.8) and 22.6% (20.08 - 25.22) at school; 8.3% (6.4 - 8.58) and 6.9% (6.0 - 8.3) on transportation, and 6.9% (3.02 - 10.42) and 4.7% (2.0 - 8.4) in other microenvironments, respectively. Time activity patterns did not differ between asthmatics and non-asthmatics in any microenvironment (home p-value=0.852; school p-value=0.259; transportation p-value=0.662; other p-value=0.393).

Table 2 shows the average exposure concentrations in each microenvironment. The overall median BC, UFP, and LDSA concentrations were 1.72 $\mu g/m^3$, 10.7 x 10^3 particles/cm^3, and 31.2 $\mu m^2/cm^3$, respectively. The highest BC and UFP concentrations were attributed to transportation (3.34 $\mu g/m^3$ and 19.1 x 10^3 part./cm^3, respectively), followed by others, school, and home. The highest LDSA concentration was also measured during transportation (50.6 $\mu m^2/cm^3$) but followed by others, home and school.

BC, UFP, and LDSA concentrations decreased with increasing age and height (Table S1). Boys had higher levels than girls, in particular for BC. Mother smoking at home increased the BC and LDSA levels at home. Higher maternal education tended to decrease the concentrations. BC was lower in the warm season.

Overall BC median concentrations were similar between asthmatics (1.69 $\mu g/m^3$) and non-asthmatics (1.72 $\mu g/m^3$), although concentrations were somewhat higher in current asthmatics (1.98 $\mu g/m^3$) (Table 3). Overall UFP concentrations were higher in asthmatic children (11.2 10^3 part./cm^3) than in non-asthmatics (9.2$10^3$ part./cm^3) (Table 3). However when age of the child was considered, the difference between the two groups was reduced from 2.0 10^3 part./cm^3 to 0.03 10^3 part./cm^3. Overall LDSA concentrations were slightly higher in asthmatic children (36.4 $\mu m^2/cm^3$) than in non-asthmatics (28.0 $\mu m^2/cm^3$), although differences did not reach statistical significance. There were no

differences in terms of overall BC, UFP and LDSA concentrations between past and current asthmatics. Per each microenvironment, concentrations of any pollutant were similar between asthmatics and non-asthmatics, even considering past and current asthmatics.

A high-to-moderate correlation was found between the overall median BC and UFP personal concentrations (Pearson r=0.65; p-value: <0.01) (Figure 2). When splitting by microenvironments we found higher correlations between BC and UFP for others (r=0.82; p-value: <0.01) and transportation (r=0.73; p-value: <0.01), than for school (r=0.62; p-value: <0.01) and home (r=0.56; p-value: <0.01) microenvironments. This correlation pattern was found in both groups (see Figure 2).

Table 1. Characteristics of the study population.

Characteristics	**Non-asthmatics (n=50)**	**Asthmatics**		
		All (n=50)	**Past (n=29)**	**Current at age 9 (n=21)**
Age (years) (mean ± SD)	9.13 ± 0.56	8.76 ± 0.61	8.77 ± 0.50	8.44 ± 0.75
Sex of the child (n, %)				
Female	27 (54%)	21 (42%)	14 (48%)	7 (33%)
Male	23 (46%)	29 (58%)	15 (52%)	14 (67%)
Height (m) (mean ± SD)	1.37 ± 0.06	1.34 ± 0.06	1.33 ± 0.06	1.35 ± 0.06
BMI at 9 years (kg/m^2) (mean ± SD)	17.54 ± 0.35	17.97 ± 3.24	18.14 ± 2.94	17.96 ± 3.69
Mother education level (n, %)				
Primary or less	6 (12%)	9 (18%)	6 (21%)	3 (14%)
Secondary	25 (50%)	23 (46%)	15 (52%)	8 (38%)
University degree	19 (38%)	16 (32%)	7 (24%)	9 (43%)
missing data (n, %)	0 (0%)	2 (4%)	1 (3%)	1 (5%)

Father education level (n, %)				
Primary or less	13 (26%)	17 (34%)	8 (28%)	9 (43%)
Secondary	26 (52%)	19 (38%)	15 (52%)	4 (19%)
University degree	11 (22%)	13 (26%)	5 (17%)	8 (38%)
missing data (n, %)	0 (0%)	1 (2%)	1 (3%)	0 (0%)
Mother smoking at home (n, %)				
Yes	9 (18%)	10 (20%)	6 (21%)	4 (19%)
No	41 (82%)	40 (80%)	23 (79%)	17 (81%)
Gas cooking (n, %)				
Yes	22 (44%)	25 (50%)	16 (55%)	9 (43%)
No	28 (56%)	25 (50%)	13 (45%)	13 (57%)
Season when PEM was performed (n, %)				
Cold (Autumn, Winter)	35 (70%)	21 (42%)	11 (38%)	10 (48%)
Warm (Spring, Summer)	15 (30%)	29 (58%)	18 (62%)	11 (52%)

No missing data reported in a specific variable, if no missing occurred in any group.

Abbreviations: BC: black carbon; BMI: body mass index; LUR: land use regression model; PEM: personal exposure monitoring.

Figure 1. Daily time-activity patterns of asthmatic and non-asthmatic children.

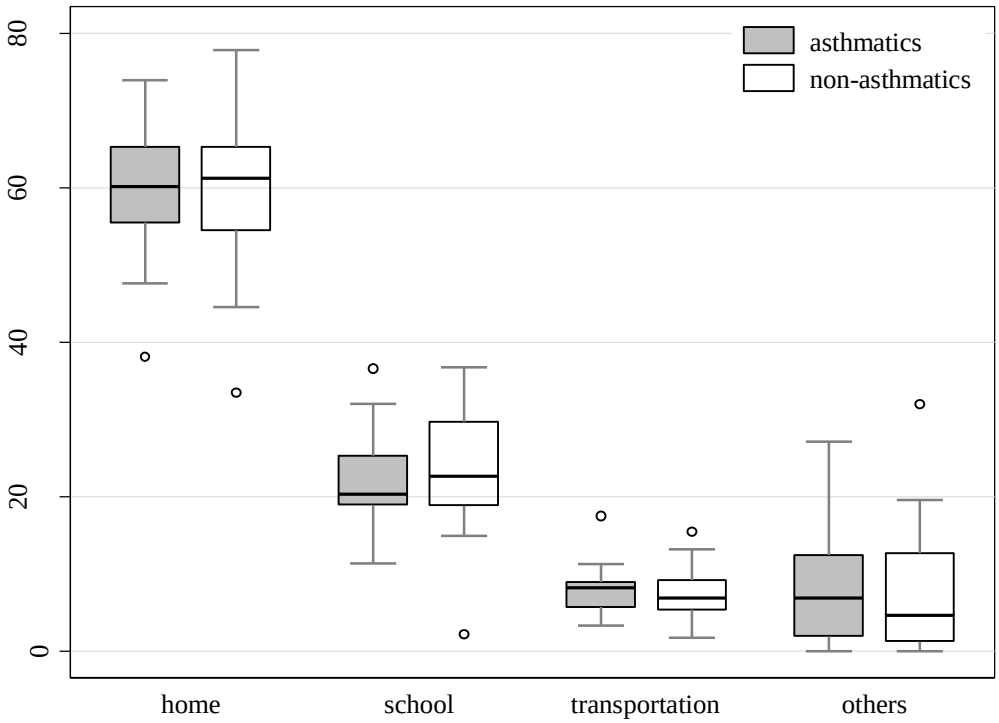


Table 2. Distribution of the average exposure concentrations of BC (μg/m^3), UFP number (part./cm^3) and LDSA (μm^2/cm^3) concentrations.

		N	Min.	p5	p25	p50	GM	GSD	p75	p95	Max.
BC (μg/m^3)	**Overall**	85	0.12	0.84	1.28	1.72	1.64	1.59	2.10	3.28	4.21
	Home	89	0.11	0.62	1.17	1.54	1.51	1.69	2.10	3.29	5.75
	School	76	0.15	0.79	1.28	1.65	1.68	1.85	2.22	4.33	5.46
	Transportation	75	1.14	1.50	2.41	3.34	3.31	1.59	4.99	7.54	8.37
	Others	66	0.14	0.99	1.34	2.20	2.23	2.09	3.46	7.08	22.02
UFP (x10^3 part./cm^3)	**Overall**	76	3.0	5.7	7.9	10.7	11.0	1.52	13.3	18.0	24.6
	Home	88	1.2	3.8	7.0	10.0	10.1	1.70	13.7	20.1	29.8
	School	76	3.1	4.7	7.1	10.2	10.6	1.59	14.8	20.8	31.1
	Transportation	71	5.8	7.6	13.6	19.1	19.7	1.55	24.2	35.9	51.0
	Others	63	5.1	5.9	8.8	14.2	15.9	1.97	23.8	52.1	134.0
LDSA (μm^2/cm^3)	**Overall**	76	8.7	14.1	26.1	31.2	36.1	1.63	41.4	68.0	252.8
	Home	88	3.7	13.6	23.8	33.4	36.3	1.84	48.1	82.1	300.5
	School	76	6.3	14.4	22.0	28.5	30.1	1.64	41.5	69.4	87.7
	Transportation	71	16.1	20.2	34.0	50.6	53.2	1.59	69.1	110.6	158.6
	Others	63	14.3	19.4	26.9	40.4	44.8	1.95	57.6	169.2	390.2

Abbreviations: BC: black carbon; GM: geometric mean; GSD: geometric standard deviation; LDSA: alveolar lung deposited surface area; Max: maximum; Min: minimum; p: percentile; UFP: ultrafine particles number.

Footnote: The overall BC, UFP and LDSA missing data are due to the applied inclusion criteria for MicroAeth and DiSCmini data independently. When looking at the different microenvironments the data missingness vary due to the added smartphone data inclusion criteria.

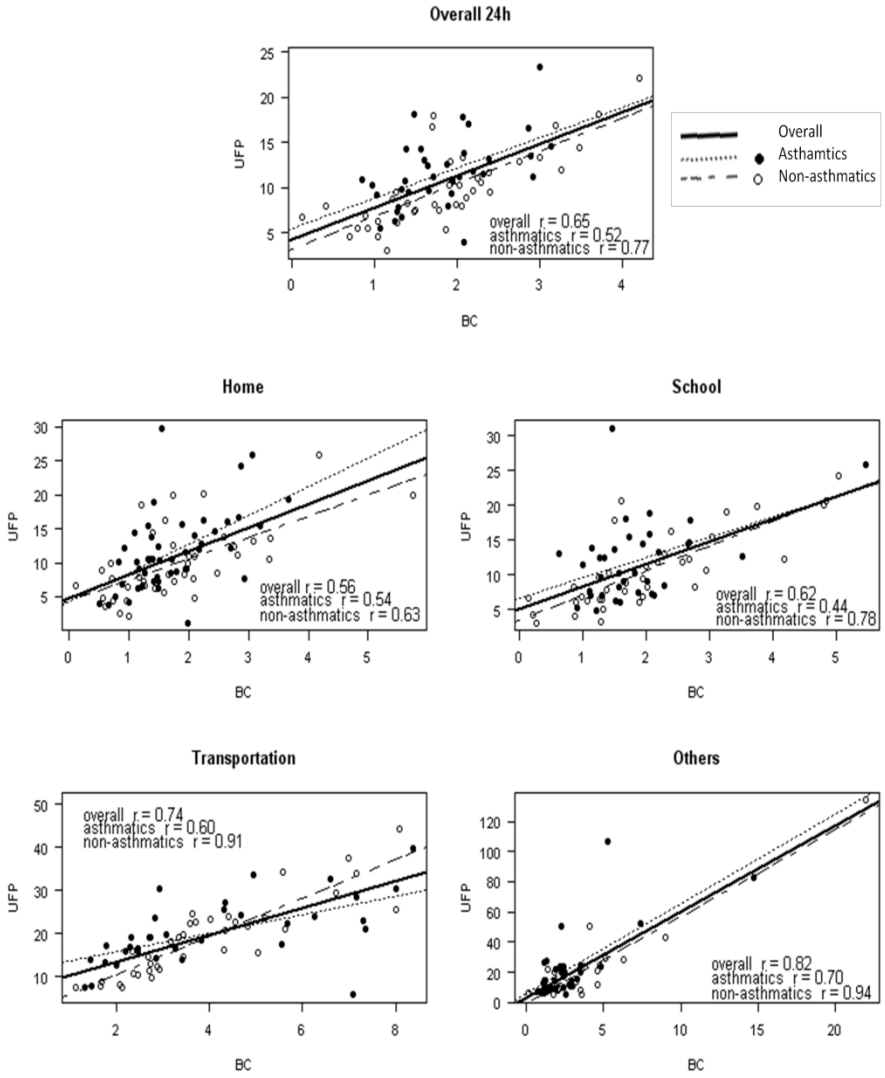
Table 3. Average exposure concentrations (median (95% CI)) of BC (μg/m^3), UFP (10^3 part./cm^3) and LDSA (μm^2/cm^3) in each microenvironment in non-asthmatics and asthmatics.

		Asthmatics		
Main Exposure Concentrations Variables	Non-asthmatics (n=50)	All (n=50)	Past (n=29)	Current at age 9 (n=21)
Overall BC exposure (μg/m^3)	1.72 (1.43-2.01)	1.69 (1.39-2.01)	1.65 (1.39-1.93)	1.98 (1.34-2.36)
N	45	40	22	18
Home	1.59 (1.27-1.95)	1.48 (1.37-1.92)	1.48 (1.34-1.91)	1.54 (1.15-2.31)
N	44	45	26	19
School	1.67 (1.38-2.14)	1.62 (1.41-1.97)	1.58 (1.22-1.94)	1.75 (1.32-2.47)
N	40	36	20	16
Transportation	3.44 (2.76-4.31)	3.13 (2.62-4.47)	3.01 (2.22-4.26)	4.31 (2.72-6.83)
N	39	36	20	16
Others	1.98 (1.71-3.48)	2.27 (1.53-2.7)	2.38 (1.85-2.87)	1.67 (1.11-2.94)
N	34	33	18	15
Overall UFP exposure (x10^3 part./cm^3)	9.2 (7.9-10.9)	11.2 (10.4-12.8)*	11.2 (9.5-12.8)	11.2 (9.7-14.6)
N	40	38	21	17
Home	8.5 (7.2-10.7)	10.5 (8.8-12.6)	10.5 (8.1-13.00)	10.6 (8.4-15.0)
N	43	45	26	19
School	9.4 (7.5-11.9)	12.5 (9.1-13.8)	10.2 (7.5-13.7)	12.9 (9.1-17.9)
N	39	37	21	16
Transportation	19.5 (14.6-22.8)	19.0 (16.6-23.0)	16.8 (14.3-23.6)	19.8 (17.7-29.3)
N	38	35	20	15
Others	11.3 (8.8-15.0)	16.6 (12.8-23.5)	19.7 (14.4-23.9)	14.2 (9.2-26.5)
N	32	32	17	15
Overall LDSA exposure (μm^2/cm^3)	28.0 (26.1-34.7)	36.4 (30.3-38.6)	36.1 (28.8-38.6)	37.6 (26.6-51.6)
N	40	38	21	17
Home	29.4 (24.5-40.5)	35.7 (31.4-43.)	35.1 (29.1-42.7)	38.1 (27.2-54.7)
N	43	45	26	19

School	29.4 (22.5-32.8)	28.4 (25.7-33.7)	27.4 (23.0-31.9)	37.5 (26.4-44.5)
N	39	37	21	16
Transportation	52.1 (38.7-63.4)	50.5 (41.0-62.9)	46.8 (32.6-61.8)	61.3 (43.1-88.6)
N	38	35	20	15
Others	31.9 (27.4-41.5)	45.8 (35.7-55.3)	46.2 (41.4-61.8)	35.7 (24.1-62.5)
N	32	32	17	15

Abbreviations: p: percentile; BC: black carbon; UFP: ultrafine particles; LDSA: alveolar lung deposited surface area; SD: standard deviation.
Footnote: The overall BC, UFP and LDSA missing data are due to the applied inclusion criteria for MicroAeth and DiSCmini data independently. When looking at the different microenvironments the data missingness vary due to the added smartphone data inclusion criteria.

Figure 2. Pearson correlations between BC (μg/m^3) and UFP (x10^3 part./cm^3) concentrations in overall microenvironments and in each one.



Abbreviations: BC: black carbon; UFP: ultrafine particle number.

4. DISCUSSION

Our results suggest that asthmatic children were exposed to similar BC, UFP, and LDSA concentrations than non-asthmatics. No between-group differences in exposure concentrations were found by type of microenvironment, nor when considering past and current asthmatic children, separately. We observed high-to-moderate correlations between personal BC and UFP exposures.

The daily time-activity patterns based on the smartphone geolocation data of each child showed no differences between asthmatic and non-asthmatic children. Children spent most of the time at home (60-61%), followed by school (20-23%) and transportation (8-7%). These percentages were very similar to those reported in Mazaheri et al. (2014) and Buonnano et al. (2013), where school children aged 8-11 years of age from Australia and Italy, spent 65% and 64% of their time at home, 28% and 24% at school, and 3% and 4% commuting, respectively. Both studies assessed time-activity patterns by using travel activity diaries, which is in good agreement to data obtained from smartphone[40]. However, travel activity diaries are limited by recall bias, reliability, reproducibility and compliance[43]. This may explain the highest proportion of time spent on transportation observed in our study compared to the other ones.

The overall median BC personal concentrations observed in our study were higher than those reported by Nieuwenhuijsen et al. 2015, who followed 45 children aged 7-11 years from Barcelona during 48 h period (GM=1.4 $\mu g/m^3$); and lower than those observed by Buonnano et al. (2013), who followed 100 children aged 8-11 years during 48 h period from Cassino (Italy) (median: 3.8 $\mu g/m^3$). Regarding studies conducted in asthmatic children, our concentrations are similar to EC concentrations reported in New York (US)[44] (mean: 1.9 $\mu g/m^3$) and higher than those reported in Los Angeles (US)[30] (mean: 0.59 $\mu g/m^3$). Median UFP and LDSA personal concentrations in our study were similar to urban background concentrations[45-46] (7 $x10^3$ part./cm^3; 37 $\mu m^2/cm^3$, respectively), and lower than those reported in Buonnano et. al (2012 and 2013) assessing personal exposure to UFP (22 x 10^3 part./cm^3 and 59-190 $\mu m^2/cm^3$, respectively). Children from Cassino and Barcelona seem to

be more exposed to personal BC and UFP, however Sabadell also has high levels of traffic related air pollutants[47]. Transportation was the microenvironment in which the highest BC, UFP, and LDSA concentrations were measured[22,48] but it was the microenvironment where the children spent least time during a day. We observed that asthmatics and non-asthmatics were exposed to similar BC, UFP, and LDSA concentrations both overall and at any microenvironment. Asthmatics at 9 years were exposed to higher UFP than non-asthmatics, but when age of the child when PEM was performed was considered, this difference disappeared.

We found moderate correlations between BC and UFP for the overall 24 h exposure, which were high for transportation and others microenvironments[16,49-50]. Indeed, BC and UFP are often well correlated in urban air because of similar sources such as vehicle exhaust emissions[45]. On the contrary, we found lower correlations between BC and UFP for home and school than for transportation which could be due the smaller range in concentrations in those microenvironments. This suggests that at home and school there could be non-traffic related UFP sources such as cooking and cleaning activities, occupational density, type of classroom board, and candle burning that may explain these low correlations[51-54].

The main strength of our study is the personal monitoring exposure assessment of BC and UFP incorporating daily mobility patterns, which introduce less error on exposure assessment than individual-level exposure estimates[55]. Another strength of the study is the use of new smartphone technology which allows assessing objectively the time activity patterns and hence the microenvironments that contributed mostly to the overall TRAP exposure of a child. Finally, the case-control study design led us to compare daily personal exposure to TRAP between asthmatic and non-asthmatic children of the same age.

The major limitation of the study is the small sample size which may have hindered the identification of differences between asthmatics and non-asthmatics. Another limitation is the short-term (24 h) monitoring period which could have been insufficient to capture the daily exposure variability. All children were followed during school days to reflect the daily TRAP exposure of a child

during the major part of the year, however we cannot dismiss confounding by sampling day. Children were instructed to continue their routine activities in order to avoid behavioral modifications. Another limitation is that asthma was self-reported by the mother and therefore outcome misclassification cannot be ruled out. In our study we distinguished between past and current asthmatics because children with asthma symptoms during the first years of life may not develop asthma later on; these division allowed us to see differences in air pollutants concentrations between groups although they did not differ. Another limitation is that we did not correct air pollution personal concentrations for background concentrations (i.e. BC and UFP variations between days across the study area). The cross-sectional design of our study did not allow us to establish causality between TRAP exposures and asthma incidence. Longitudinal studies are needed to reveal whether the concentrations of BC and UFP are associated with a higher risk of asthma at school age[56].

In conclusion, our study suggests that asthmatic and non-asthmatic children had a similar time activity pattern and similar average exposures to BC, UFP, and LDSA concentrations. This suggests that interventions should be tailored to general population, rather than to subgroups defined by disease.

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Conflict of interest

The authors declare no competing financial interest.

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