The EuroLifeNet Study: How Different Microenvironments Influence Personal Exposure to PM$_{2.5}$ among High-School Students in Milan

Alessandro Borgini$^{*}$, Cristian Ricci$^2$, Martina Bertoldi$^1$, Paolo Crosignani$^1$, Andrea Tittarelli$^1$

$^1$Fondazione IRCCS Istituto Nazionale dei Tumori, Cancer Registry and Environmental Epidemiology Unit, Via Venezian 1, Milan, Italy
$^2$Institut für Epidemiologie und Präventivmedizin, Universität Regensburg Fakultät für Medizin, Regensburg, Germany
Email: Alessandro.Borgini@istitutotumori.mi.it

Received 12 February 2015; accepted 6 March 2015; published 13 March 2015

Abstract

Background: Epidemiological studies show that long-term exposure to PM is associated with an increased risk of cancer. The EuroLifeNet study measured the personal exposure to PM$_{2.5}$ in 90 pupils attending three schools in Milan, using a portable nephelometer, over a three-week period spanning November and December 2006. Background levels explained 40% of the variability of the exposure. Methods: As a second part of that study we analyzed the role of different microenvironments as determinants of personal exposure to PM$_{2.5}$. Results: Exposure was influenced by the time of day, zone of the city and different microenvironments. Exposure was higher indoors than out, and indoors it was higher in the kitchen, particularly during cooking. In outdoor environments exposure was higher at bus stops where road traffic was heavy. Conclusions: Even though background concentration can be a good predictor of personal exposure to PM, students' personal exposure is strongly influenced by different microenvironments and should be considered in population studies. The EuroLifeNet experience gives a contribution to personal exposure measure methodology.

Keywords

Personal Exposure, Air Pollution, Fine Particles, Students, Schools, Indoor/Outdoor, Microenvironments

*Corresponding author.

1. Introduction

Many epidemiological studies show that air pollution and long-term exposure to atmospheric particulate matter (PM) are associated with an increased risk of specific cancers [1]-[3]. Studies on school-age children show an association between PM and adverse effects on respiratory function [4]-[7]. In epidemiological studies population’s exposure to PM is generally estimated from fixed monitoring stations which afford standardized measurements of atmospheric pollutant outdoor concentrations on a daily or hourly basis. Although pollutant levels measured by monitoring stations in a general way reflect the exposure of individuals to pollutants in the area, they cannot accurately estimate the individual exposure, which has been shown to be profoundly affected by individual behavior.

Personal exposure levels to air pollution and in particular to fine particles (PM$_{2.5}$) are influenced by mode of transports, route and type of vehicle [8]-[10] and indoor emission sources (smoking and cooking). Some studies found that exposure to the particulate matter was higher in bus stops [11] and cars than during walking or cycling [12].

Some recent studies report that in children travelling by bus or car in slow-moving rush-hour traffic exposure may be significantly raised [13]-[17]. In this paper we present the results of personal exposure monitoring campaign conducted in the context of EuroLifeNet project.

The EuroLifeNet program was designed by the Research Centre on Information Technologies and Participatory Democracy (CITIDEP) with the support of the Institute for Environment and Sustainability (IES) of the Joint Research Centre (JRC) of the European Commission (website http://www.citidep.pt/eurolifenet/, accessed on 30 June 2014). Its aims are to measure personal exposure to particulate matter (PM$_{10}$ and PM$_{2.5}$) and raise awareness, particularly among school students, of the hazards of air pollution. In the first pilot project of EuroLifeNet, carried out in Portugal and Italy, school students gathered data on personal exposure to PM$_{2.5}$ using portable nephelometers.

2. Methods

2.1. Nephelometer

Personal exposure was monitored using SidePak (TSI Inc., Model AM510, Shoreview, MN, USA) portable nephelometers (see material and methods of EuroLifeNet first published paper [18]). During the study, the instruments were calibrated each weekend by the Institute for Environment Sustainability (IES) of the Joint Research Centre (JRC), Ispra, Italy (see EuroLifeNet 1 [18]). Moreover, at the beginning of the study a zero filter was attached to each instrument inlet for the zeroing process.

2.2. Data Collection

Ninety pupils from three Milan schools (Feltrinelli, Cremona, Rinascita) were involved in the project, which lasted 3 weeks during November and December 2006; ninety students were involved, 57 males and 33 females; age ranged from 12 to 18 years old. Six nephelometers were available for the study; each was used by a different pupil each day. Six different students (two for each school) were involved every day, each one having a nephelometer for a 24-hour period. This way we had six simultaneous measurements in six different places, representing estimations of personal exposure and not of background level.

Teachers and pupils were instructed on correct instrument use. The instrument was placed in the classroom at the beginning of each run period (at about 12.00 a.m.) close to the pupil entrusted with it for that day. When pupils moved, in particular when they went home, they took the instrument with them carrying it in a bag mounted on the belt, with the inlet tube placed in the breathing zone, so that the inlet was always exposed. When pupils were at home they were instructed to keep the instrument in the room they mainly occupied, and to place it in their bedroom overnight [19]. The following morning the instrument was carried to school and remained in the classroom with the pupil during the first hour (until about 9.00 a.m.). So the total monitoring period for each pupil was about 21 h.

Each pupil was also educated by the teachers to complete a Time Activity Diary (TAD), when carrying the nephelometer, reporting his/her location and activity [20] [21]. The TAD recorded each pupil’s personal information and time-activity patterns, including home location, traffic-related information and proximity to possible outdoor and indoor emission sources, e.g. when road traffic was heaviest (outdoor emission) or during cooking (indoor emission). Hour by hour students filled the TAD indicating every useful information.
In this second part of the study we made a detailed analysis of personal exposure of PM$_{2.5}$ in relation to the TAD circumstances, i.e. the means of transports used to and from school, and information on indoor exposure sources. Moreover, it was possible to consider active or passive smoking confounder because students reported if they were smoking or there was someone smoking near them.

To calculate PM$_{2.5}$ exposure in each microenvironment we compared each nephelometer’s data (which reported day and time joined with the measurement of the instrument) and the indication reported hour by hour by the students in their TAD.

### 2.3. Statistical Methods

On the basis of the TAD we considered eight microenvironments, four classified as indoor (classroom, kitchen, bedroom, living room) and four as outdoor (private cars, public bus, bus stop, on street). Indoor PM$_{2.5}$ exposure was calculated aggregating any indoor environment. Sub-analyses were performed on three groups: bedroom and living room together, kitchen, classroom. Outdoor PM$_{2.5}$ exposure was examined in a similar fashion. We first aggregated all outdoor measures and then we focused on the means of transports (private cars, public bus) and bus stop joined to street.

Background exposure to PM$_{2.5}$ was calculated including in the analysis correction for the day, time of day (morning, afternoon, evening, night), zone of the city (where the school was located) and pupils (considered the sample unit). Differences between micro-environmental PM$_{2.5}$ exposures and background were then calculated and considered as an estimate of the exposure completely attributable to the different microenvironments.

Descriptive statistics of PM$_{2.5}$ exposure for each microenvironment used the mean, median, quartiles and standard deviation over the overall observation period. To highlight skewness in PM$_{2.5}$ exposures the data were graphically reported by microenvironment using frequency histograms. A generalized linear model was applied to detect differences between microenvironment PM$_{2.5}$ exposures and background. Multiple comparisons between microenvironments were done using the Bonferroni correction and reported using least squares (LS) means and 95% confidence limits (CIs). To investigate the relation between PM$_{2.5}$ exposures and time and to highlight PM$_{2.5}$ exposure peaks, the relation between PM$_{2.5}$ exposure and time was graphically reported for each microenvironment. All statistical analysis was done using SAS software package vers. 9.1.3. [22].

### 3. Ethical Issues

All the participants were volunteers, and preliminary meetings to present the project were held at each school to explain and clarify all aspects. All procedures were performed in compliance with relevant laws and institutional guidelines. Informed consent of the students and their parents was obtained while compiling Time Activity Diaries. Data processing and storage were kept confidential and during the analysis personal identification data were separated from the nephelometer and TAD information.

### 4. Results

Descriptive statistics and histogram plots of PM$_{2.5}$ exposure over the whole observation period showed that exposure was skewed for every microenvironment under analysis (Figure 1, Figure 2 and Table 1). Descriptive statistics (Table 1) indicated that PM$_{2.5}$ exposure was generally higher in indoor microenvironments than outdoors. In addition, exposure on public buses seemed higher than in private cars. Exposure was also high at bus stops and in the kitchen.

Background PM$_{2.5}$ exposure was calculated considering the sampling day, time of day, zone of the city and pupils. All these factors introduced in a nested generalized linear model resulted in an $R^2$ of 0.61 which corresponds to an explained variance of about 60%, the remainder being explained by other sources of variability such as micro environmental exposure or other random factors.

The statistical comparison among microenvironments (Table 2) showed that PM$_{2.5}$ exposure was significantly different for some microenvironments.

Among these microenvironments PM$_{2.5}$ exposure was high at bus stops and in the kitchen where the excesses were respectively 12.82 (95% CI, 2.2 - 23.4) and 29.38 (95% CI, 25.5 - 33.6) μg∙m$^{-3}$. Among means of transport, PM$_{2.5}$ exposure appeared higher for public buses than private cars: the difference was 9.9μg∙m$^{-3}$ (95% CI, 2.1 - 17.7).
Figure 1. Histograms of PM$_{2.5}$ exposure by microenvironment (outdoor).

![Histograms of PM$_{2.5}$ exposure by microenvironment (outdoor).](image)

Table 1. Descriptive statistics by microenvironment.

<table>
<thead>
<tr>
<th>Microenvironment</th>
<th>Mean</th>
<th>Median</th>
<th>First Quartile</th>
<th>Third Quartile</th>
<th>Standard Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Outdoor</td>
<td>46.0</td>
<td>38.5</td>
<td>22.0</td>
<td>65.0</td>
<td>30.2</td>
</tr>
<tr>
<td>Inside private car</td>
<td>40.6</td>
<td>33.5</td>
<td>23.3</td>
<td>50.9</td>
<td>27.2</td>
</tr>
<tr>
<td>Inside public bus</td>
<td>52.9</td>
<td>48.5</td>
<td>29.5</td>
<td>69.0</td>
<td>31.4</td>
</tr>
<tr>
<td>On street/at bus stop</td>
<td>71.3</td>
<td>63.8</td>
<td>50.8</td>
<td>101.0</td>
<td>34.9</td>
</tr>
<tr>
<td>Indoors</td>
<td>53.6</td>
<td>42.5</td>
<td>28.8</td>
<td>66.7</td>
<td>35.2</td>
</tr>
<tr>
<td>Kitchen</td>
<td>69.3</td>
<td>62.3</td>
<td>49</td>
<td>76.3</td>
<td>35.7</td>
</tr>
<tr>
<td>In the classroom</td>
<td>39.4</td>
<td>30.3</td>
<td>19.8</td>
<td>55.5</td>
<td>27.2</td>
</tr>
<tr>
<td>Bedroom and living room</td>
<td>35.1</td>
<td>24.5</td>
<td>13.8</td>
<td>48.5</td>
<td>31.0</td>
</tr>
</tbody>
</table>

The scatter plot of PM$_{2.5}$ exposure over time showed that exposure was closely influenced by time (Figure 3). As expected, kitchen PM$_{2.5}$ exposure was higher between 12.00 - 14.00 p.m. and 18.00 - 21.00 p.m., corresponding to lunch and dinner cooking periods; this effect was glaring for all indoor microenvironments (Figure 3—indoor panel). PM$_{2.5}$ exposure at bus stops was higher during the period 13.00 - 15.00 p.m. and 17.00 - 19.00 p.m. and in the early morning (07.00 a.m.) when car traffic in the city was highest (Figure 3—bus stop panel).
Figure 2. Histograms of PM$_{2.5}$ exposure by microenvironment (indoor).

Table 2. PM$_{2.5}$ exposure differences between microenvironment.

<table>
<thead>
<tr>
<th></th>
<th>Private Cars</th>
<th>Public Bus</th>
<th>Bus Stop</th>
<th>Kitchen</th>
<th>Classroom</th>
<th>Sleeping &amp; Living Room</th>
<th>Outdoor</th>
<th>Indoor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Private cars</td>
<td>0.53</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>[−7.0; 8.0]</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Public bus</td>
<td></td>
<td>9.9*</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>[2.1; 17.7]</td>
<td></td>
<td>[3.2; 17.6]</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bus stop</td>
<td>12.2**</td>
<td></td>
<td>2.3</td>
<td></td>
<td>12.8*</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>[4.0; 16.2]</td>
<td></td>
<td>[−5.8; 10.4]</td>
<td></td>
<td></td>
<td>[2.2; 23.4]</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kitchen</td>
<td>28.8**</td>
<td>18.2**</td>
<td>16.6**</td>
<td></td>
<td>29.4**</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>[22.9; 34.7]</td>
<td></td>
<td>[10.4; 26.0]</td>
<td></td>
<td></td>
<td>[7.1; 26.10]</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>[25.2; 33.6]</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Classroom</td>
<td>0.41</td>
<td>10.4*</td>
<td>12.3*</td>
<td></td>
<td>28.9**</td>
<td>0.12</td>
<td></td>
<td></td>
</tr>
<tr>
<td>[−6.1; 6.9]</td>
<td></td>
<td>[3.9; 16.9]</td>
<td></td>
<td></td>
<td>[10.4; 20.1]</td>
<td>[21.7; 36.1]</td>
<td>[−3.4;3.6]</td>
<td></td>
</tr>
<tr>
<td>Sleeping &amp; living room</td>
<td>7.8*</td>
<td>2.1</td>
<td>4.5</td>
<td>21.1**</td>
<td>8.2*</td>
<td>8.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>[1.1; 14.5]</td>
<td>[−4.7; 8.9]</td>
<td>[−2.0; 11.0]</td>
<td>[14.3; 27.9]</td>
<td>[1.6; 14.8]</td>
<td>[−1.7; 18.2]</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Outdoor</td>
<td>1.3</td>
<td>9.2*</td>
<td>10.0*</td>
<td></td>
<td>28.1**</td>
<td>1.1</td>
<td>7.0*</td>
<td></td>
</tr>
<tr>
<td>[−4.6; 7.2]</td>
<td></td>
<td>[3.4; 15]</td>
<td>[3.2; 16.8]</td>
<td></td>
<td>[19.9; 36.3]</td>
<td>[−4.8; 7.0]</td>
<td>[0.2; 13.8]</td>
<td>[−3.7; 7.3]</td>
</tr>
<tr>
<td>Indoor</td>
<td>21.1</td>
<td>2.1</td>
<td>0.2</td>
<td>8.3**</td>
<td>12.4**</td>
<td>4.3</td>
<td>19.3**</td>
<td>12.6**</td>
</tr>
<tr>
<td>[13.6; 28.6]</td>
<td></td>
<td>[−4.1; 8.3]</td>
<td>[−5.7; 5.9]</td>
<td></td>
<td>[2.4; 14.1]</td>
<td>[6.1; 18.7]</td>
<td>[−2.1; 10.7]</td>
<td>[13.1; 25.5]</td>
</tr>
</tbody>
</table>

*P ≤ 0.01; **P ≤ 0.001. The comparison between microenvironments and background PM$_{2.5}$ exposure was reported on the diagonal.
5. Discussion

Children’s exposure could be described and simplified as due to air pollution concentrations in three microenvironments: home, school and transport. In the period considered outdoor activities, e.g. sports or walking were rare (in winter time students are more often at school or at home). The strong positive skewness was mostly due to some PM$_{2.5}$ exposure peaks observed during the sampling period. This feature was common to all the microenvironments considered, particularly indoor microenvironments such as the kitchen [23], or outdoor microenvironments such as bus stop and others [24]. This difference is presumably due to indoor sources of exposure like cooking at home or science laboratories at school. Indoor PM$_{2.5}$ is affected by ambient concentrations, air exchange rates, penetration factors, as well as deposition and resuspension [25].

In different articles comparing indoor and outdoor exposure, PM concentrations were generally higher indoors [26], as also reported in studies such as the European Project EXPOLIS [27]-[31]. Cooking, cleaning and particularly smoking result in the formation of PM$_{2.5}$ and others contaminants in indoor air [32]-[34].

Although children spend less time in transport than at home or school, the data suggest that travel could be an important source of exposure; in fact, as reported in the study by Yip et al. [35], we too found high PM$_{2.5}$ concentrations in the outdoor microenvironments, and this was related to the time children spent near main roads with heavy traffic, at bus stops or in moving buses [36].

Children’s exposure to air pollution according to different transport modes and microenvironments has been considered in many studies [37]-[40] but it is still hard to quantify exactly the differences in air pollution exposure in relation to children’s behaviour. The most plausible reason is that most studies compare measurements taken in different means of transport, but in different moments of the day and not simultaneously, so they are influenced by variations in background level.

In EuroLifeNet study children’s exposure is measured close to the breathing zone to give a good estimate of the inhaled concentration. The breathing zone is much closer to the main emission sources of motor vehicles than city background fixed-site monitors. Fine particulate matter levels in different microenvironments are largely

![Figure 3. Histograms of PM$_{2.5}$ exposure by microenvironment (outdoor).](image-url)
determined by outdoor and indoor emission sources. However, concentrations in enclosed locations from indoor sources can be higher and even children’s behaviour can significantly influence exposure levels.

The principle limitations of this study are the limited period of data collection (only three weeks in autumn time, it would have been surely better to have more campaigns in different seasons) and the fact that student’s movements and locations were ascertained only on the basis of what they reported on the TAD, because for this study was not possible to equip the students also with a GPS instrument, in order to report their movements on a map.

6. Conclusion

EuroLifeNet study was designed to measure personal exposure, indoor and outdoor levels of PM$_{2.5}$ concentrations of pupils of three high schools in Milan. The first analysis showed a good correlation between daily PM$_{2.5}$ background concentrations and personal exposure measured by the nephelometers. This second part of the study evidenced that students’ personal exposure was influenced by the microenvironment in which they spent their time. In summary, we found that the daily variability of personal exposure could be well estimated by the daily variability of background concentrations (the indicator mostly used in epidemiological studies on health effects of PM exposure), but the real extent of the exposure, attainable only using portable instruments such as the nephelometers, was generally higher in terms of concentrations levels.

Competing Interests

The authors declare that they have no competing interests.

Acknowledgements

The authors are grateful to Emile De Saeger, former European Commission, Joint Research Centre, Institute for Environment and Sustainability, Transport and Air Quality Unit, Ispra (Varese, Italy) for scientific support and project coordination, to Rita Gaudioso for checking the students’ diaries (TAD), to J. D. Baggott for revising English, to Genitori AntiSmog for the organization and motivation of the EuroLifeNet project, to Assoutenti for logistic support, to the teachers of the Cremona, Rinascita, and Feltrinelli schools, and to all the students who participated enthusiastically in the project.

References


[19] Sorensen, M., Steffen, L., Andersen, V.H., Raaschou-Nielsen, O., Skovgaard, L.T., Knudsen, L.E., Nielsen, I.V. and Hertel, O. (2005) Personal Exposure to PM$_{2.5}$, Black Smoke and NO$_2$ in Copenhagen: Relationship to Bedroom and Outdoor Concentrations Covering Seasonal Variation. *Journal of Exposure Analysis and Environmental Epidemiology*, 15, 413-422. [http://dx.doi.org/10.1038/sj.ejea.7500419](http://dx.doi.org/10.1038/sj.ejea.7500419)


Abbreviations
CI: Confidence Interval; IES: Institute for Environment Sustainability; JRC: Joint Research Centre; PM$_{2.5}$: Particulate matter of aerodynamic diameter $\leq 2.5$ µm; TAD: Time Activity Diary.