Assessment of children exposure doses to ultrafine particles in primary schools

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ABSTRACT: Children attending primary schools may be largely exposed to the ultrafine particles (UFPs) present in the classroom's indoor air, which may lead to severe health consequences resultant from their increased susceptibility. Thus, this study aimed to estimate the UFP exposure dose rates in Portuguese children attending public primary schools. Ultrafine particles were sampled in 10 public primary schools located in Porto. Exposure dose rates were estimated for 488 children (aged 8 to 10 years) of the sampled schools. The estimated mean of exposure dose rates in children were $4.06 \times 10^8 \pm 0.11 \times 10^8$ part/kg.day. Specific indoor activities as well as outdoor environment conditions appeared to be associated with increased indoor UFP number concentrations and, consequently, with higher exposure doses in children attending those schools. Overall, children showed at least two times higher UFP exposure dose rates when compared to occupationally exposed adults (i.e. teachers and school staff).

1 INTRODUCTION

Currently, several guidelines and strategies have been developed in order to reduce the health risk caused by indoor exposure to particulate matter (WHO, 2005). For instance, the EnVie project showed that source control approaches and adequate ventilation are the key elements to reduce health problems related with inadequate indoor air quality, including fine and coarse particulate matter pollution (Oliveira Fernandes, 2008). However, there are no regulations regarding the concentrations of ultrafine particles (UFPs) which are particles smaller <0.1 μm and s strong source of oxidative stress and lung inflammation, possibly causing the onset or exacerbation of asthma and other respiratory diseases. The strong toxicity of UFPs is often associated to their proficiency for penetrating cell membranes (Peters et al., 1997, Penttinen et al., 2001) and consequent carcinogenic activity (Stanek et al., 2011).

In Portugal, children attendance in primary school is compulsory and, in general, they spend at least 7 hours per day in these institutions, from Monday to Friday, which may be reflected as a large period of exposure to indoor UFPs. Moreover, children tend to be more susceptible to UFPs toxicity particularly due to their immature respiratory systems, reduced constitution and minor lung function (Schwartz, 2004). To evaluate the health risk resulting from UFP pollution, several studies have been assessing the dose rates of exposure to these particles in children (Buonanno et al., 2012, 2013, Mazaheri et al., 2014). Fonseca et al. (2014) reported UFP inhalation exposure doses for children estimated at 3 Portuguese preschools; the results showed that 3 to 5 years old children presented 4 to 6 times higher dose rates than adults with similar daily schedules. Since children in primary schools spend more time than those in pre-schools, it is possible that the exposure dose rates to indoor UFPs are also higher in these indoor environments, even if similar particle number concentrations are considered.

Therefore, the aim of this study was to estimate the UFP inhalation dose rates in Portuguese children (8-10 years old) attending public primary schools. Additional objectives of this work

were: a) to estimate the exposure doses of UFPs in adults with similar schedule conditions; and b) to compare the different exposure doses between the populations of children and adults.

2 MATERIALS AND METHODS

2.1 *Sampling*

Ultrafine particles were sampled in 10 public primary schools (35 classrooms) located in the urban area of Porto (S1 to S10). More detailed information regarding the sampling sites is shown in Table 1.

Table 1. Main characteristics of the sampled schools.

School	Building location	Cooking	Number of sampled classrooms	Classroom ventilation
S1	Low traffic; mixed residential and industrial area.	No	2	Natural ventilation (small grids; inoperable windows)
S2	Low traffic; residential area.	No	4	Natural ventilation (not facing the main street)
S3	High traffic; densely packed residential area.	No	4	Natural ventilation (windows do not face the main street)
S4	Low traffic; residential area; hospital in the proximity.	No	4	Natural ventilation (windows do not face the main street)
S5	Medium traffic and metro; densely packed residential area.	Yes	4	Natural ventilation (not facing the main street)
S6	High traffic; densely packed residential area.	No	4	Natural ventilation (facing the main street)
S7	Low traffic; densely packed residential area.	No	4	Natural ventilation (windows do not face the main street)
S8	Medium traffic; densely packed residential area.	No	2	Natural ventilation (windows do not face the main street)
S9	Medium traffic; densely packed residential area.	No	3	Natural ventilation
S10	High traffic and metro; densely packed residential area.	No	4	Natural ventilation

The measurements were performed during a regular school day and under representative activities, conditions of occupancy and use of the classrooms (from 9:00 to 16:00). In general, the recess periods occurred from 10:30 to 11:00 and from 12:30 to 14:00. These were non-occupation periods and were not consider for the estimation of the exposure dose rates.

Two portable condensation particle counters (P-Track model 8525, TSI Inc., MN, USA) were used for the assessment of UFP number concentrations. The instruments were installed inside each classroom and were set to continuously measure during at least one school day. Logging intervals were set to 1 minute between each sample according to previously published studies (Norback et al., 2011, Zhang and Zhu, 2012, Fonseca et al., 2014). Further detailed characterization of the equipment has been previously reported (Matson et al., 2004).

The instruments were mounted on a flat surface at the height of the children's breathing zone (1.2 to 1.5 m) as far as possible from windows or doors as well as from major indoor sources of UFPs. A researcher supervised the sampling process and recorded relevant information.

2.2 *Exposure dose rate calculation*

In this study, 713 children attended the sampled classrooms. The children' legal guardians received an envelope with information regarding the project as well as a written consent form, in

accordance with the Helsinki declaration. The UFP exposure dose rates were calculated for all 488 (aged 8 to 10 years old) that were authorized to participate in the study (66.8%). Children's UFP exposure dose rates was calculated using the age and body weight-specific formula presented as Equation 1, which has been validated in previously published studies (Ginsberg et al., 2005, Kalaiarasan et al., 2009, Castro et al., 2011, Fonseca et al., 2014).

$$D = \left(\frac{BR_{WA}}{BW}\right) \times C_{WA} \times OF \times N \quad (1)$$

In this equation, D represents the age-specific dose rate (part./kg/day); BR_{WA} is the age-specific weighted average breathing rate (L/min); BW is the body weight of the children (kg); C_{WA} is the weighted average particle number concentrations (part./L); OF is the occupancy factor; N is the total time per day spent in the location of exposure (min/day).

The BR_{WA} is characterized by the intensity of the activity practiced at the time of exposure. Seeing as primary schoolchildren are normally seated during the time they spend in classroom (writing, studying, drawing, etc.), the "sedentary/passive" activity level was selected. The age-specific inhalation factors were retrieved from the US EPA exposure factors handbook (U.S. Environmental Protection Agency, 2011). Thus, BR_{WA} was considered as 4.8 L/min for 8 to 10 years old children. The BW of children was determined by a certified body composition analyzer (Tanita® TBF-300A, capacity 200kg, accuracy 100g) operated by a trained nurse. Children were weighted barefooted and 1 kg was deducted from the measured weight to account the clothing. The platform and handle electrodes of the scale were cleansed with 96% alcohol after each measurement. C_{WA} was estimated using the UFP average number concentrations weighted by the real time that children spent inside the classroom and the OF was always considered as 1, since children kept their schedules and their respective locations tightly. Although children are compelled to stay at least 7 hours in primary schools, the total time per day spent inside the classroom represents only 5 hours of that time period since they have 2 hours of recesses each day. Therefore, N was considered as 300 min/day (5 hours).

For comparison purposes, UFP exposure dose rates were also estimated for adults in similar conditions (aged 21 to 60 years old). When concerning "sedentary/passive" activities, the BR_{WA} in adults was considered 4.2 L/min for ages between 21 and 30, 4.3 L/min between 31 and 40, 4.8 L/min between 41 and 50, and 5.0 L/min between 51 and 60 (U.S. Environmental Protection Agency, 2011). The average BW considered for all groups of adults was 70.8 kg according to the European region average body mass in 2005 (Walpole et al., 2012).

Statistical analysis was performed using SPSS Statistics v20 (IBM). Statistical significance was considered when $p<0.05$.

3 RESULTS AND DISCUSSION

The statistical analysis showed no significant differences regarding BW between both genders ($p = 0.748$). Moreover, there were also no significant BW differences between the 10 schools ($p = 0.156$). These results suggest that, despite the differences in gender and location of the school, there are no major dissimilarities in the average BW of 8 to 10 years old primary schoolchildren.

The total mean (average and standard error of the mean) of UFP inhalation dose rates in children (8 to 10 years old) of 10 primary schools was $4.06 \times 10^8 \pm 0.11 \times 10^8$ part./kg.day. The information regarding the average inhalation dose rates in each school is summarized in Table 2. The results showed that exposure doses in children attending S5 were 1.2 to 4.8 times higher than those of other schools. These results may be associated with the increased production of UFPs resulting from the performed cooking activities; S5 was the only school in this study where meals for the children were directly cooked in the respective school building. These findings support previously published studies showing that cooking practices are significantly associated with increased UFP production (Zhang and Zhu, 2012). Schools S6 and S10 also presented dose rates above the average value, probably due to the closer proximity to roads with intense traffic, which are considered major sources of ambient UFPs that may penetrate to the indoor environment of the schools (Kulmala et al., 2004). Finally, S1 exhibited 1.8 to 4.8 lower UFP inhalation dose rates than the estimated mean. The lower traffic intensity in the school area

and the inoperable windows (ventilation only promoted by small grids) may hinder the penetrance of UFPs from the outdoors, which consequently could lead to lower dose rates in S1.

Table 2 - Average dose rates (D, part/kg.day) per school and age group.

School	Mean UFP number concentrations (part./cm^3)	Average UFP inhalation dose rates (part/kg.day)				
		Children (8 to 10)	Adults (21 to 30)	Adults (31 to 40)	Adults (41 to 50)	Adults (51 to 60)
S 1	3.37×10^3	1.48×10^8	6.00×10^7	6.15×10^7	6.86×10^7	7.15×10^7
S 2	6.58×10^3	2.96×10^8	1.17×10^8	1.20×10^8	1.34×10^8	1.39×10^8
S 3	5.68×10^3	2.65×10^8	1.01×10^8	1.03×10^8	1.16×10^8	1.20×10^8
S 4	7.35×10^3	3.17×10^8	1.31×10^8	1.34×10^8	1.50×10^8	1.56×10^8
S 5	1.49×10^4	7.06×10^8	2.65×10^8	2.71×10^8	3.03×10^8	3.16×10^8
S 6	1.25×10^4	5.85×10^8	2.23×10^8	2.28×10^8	2.55×10^8	2.66×10^8
S 7	8.78×10^3	3.71×10^8	1.56×10^8	1.60×10^8	1.79×10^8	1.86×10^8
S 8	7.61×10^3	3.43×10^8	1.35×10^8	1.39×10^8	1.55×10^8	1.61×10^8
S 9	8.36×10^3	3.76×10^8	1.49×10^8	1.52×10^8	1.70×10^8	1.77×10^8
S 10	9.21×10^3	4.26×10^8	1.64×10^8	1.68×10^8	1.87×10^8	1.95×10^8

S - School; UFP – Ultrafine particles.

To further comprehend the extent of UFP exposure in the analyzed schools, the dose rates of children were compared with those of adults. The results showed that the UFP dose rates increased with the increasing age of adults, being minimal in individuals aged from 21 to 30 years old and constantly rising as the age increases due to the higher inhalation dose rates, which is probably associated to the natural lung function loss resulting from the aging process (Harik-Khan et al., 1998). However, due to the children vulnerability and small body weight, they still showed 2.0 to 2.2 higher UFP exposure doses than the older adults (51 - 60). These results demonstrate the high susceptibility of children to UFPs and indicate that primary schools have an important role in the child's overall particle exposure.

Information regarding primary school children exposure doses to UFPs is scarce. In addition, the different study approaches and the dissimilar characteristics of the sampled indoor microenvironments hamper further comparisons. Therefore, the dose rates estimated within this work were not compared with other studies.

4 CONCLUSIONS

This is the first study estimating the UFP exposure dose rates for 8 to 10 years old children attending Portuguese primary schools. The results suggest that schools located near busy roads as well as schools with meals directly cooked in the building have higher indoor number concentrations of UFPs. However, in order to further analyze the sources of indoor UFPs in primary schools, a full walkthrough inspection concerning building characteristics is necessary.

Children susceptibility to UFP exposure was supported by this study and, when compared to adult individuals in similar conditions, they had at least two times higher dose rates, even when compared to older individuals. Therefore, a special attention should be given to the major sources of ultrafine particles in primary schools in order to minimize the exposure dose rates in children. Further investigations regarding building characteristics and sources of UFPs would be important to provide information to protect public health.

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