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Personal exposure to ultrafine particles: The influence of time-activity patterns

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HIGHLIGHTS

- Personal exposure to ultrafine particles was measured for home and full time workers.
- The average exposure and dose were higher for women during both summer and winter.
- Results show that winter exposure was higher in respect to summer.
- Cooking activities contribute in a significant way.
- The highest dose intensity activity for men was time spent using transportation.

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ABSTRACT

Exposure to ultrafine particles (UFPs) is deemed to be a major risk affecting human health. Therefore, airborne particle studies were performed in the recent years to evaluate the most critical micro-environments, as well as identifying the main UFP sources.

Nonetheless, in order to properly evaluate the UFP exposure, personal monitoring is required as the only way to relate particle exposure levels to the activities performed and micro-environments visited.

To this purpose, in the present work, the results of experimental analysis aimed at showing the effect of the time–activity patterns on UFP personal exposure are reported. In particular, 24 non-smoking couples (12 during winter and summer time, respectively), comprised of a man who worked full-time and a woman who was a homemaker, were analyzed using personal particle counter and GPS monitors. Each couple was investigated for a 48-h period, during which they also filled out a diary reporting the daily activities performed. Time activity patterns, particle number concentration exposure and the related dose received by the participants, in terms of particle alveolar-deposited surface area, were measured.

The average exposure to particle number concentration was higher for women during both summer and winter (Summer: women 1.8×10^4 part. cm^{-3}; men 9.2×10^3 part. cm^{-3}; Winter: women 2.9×10^4 part. cm^{-3}; men 1.3×10^4 part. cm^{-3}), which was likely due to the time spent undertaking cooking activities. Staying indoors after cooking also led to higher alveolar-deposited surface area dose for both women and men during the winter time (9.12×10^2 and 6.33×10^2 mm^2, respectively), when indoor ventilation was greatly reduced. The effect of cooking activities was also detected in terms of women's dose intensity (dose per unit time), being 8.6 and 6.6 in winter and summer, respectively. On the contrary, the highest dose intensity activity for men was time spent using transportation (2.8 in both winter and summer).

1. Introduction

Airborne particles are related to a range of adverse health outcomes on the human cardiovascular and respiratory systems (Cesaroni et al., 2013; Kreyling et al., 2006; Pope and Dockery, 2006; Schmid et al., 2009). The potential of particles to generate adverse respiratory and systemic health effects is related to their capacity to enter the lungs, potentially carrying several toxic compounds with them. At present, it is not known which particle size, morphology or chemical component is most strongly related to the adverse outcomes on human health and further research in this field is required. In terms of particle size, attention has shifted from mass (PM_{10} or $PM_{2.5}$, mass concentration of particles smaller than 10 μm and 2.5 μm in aerodynamic diameter, respectively, collected on a filter) to surface area and particle number concentrations (Cauda et al., 2012; Franck et al., 2011; Giechaskiel et al., 2009), whose prevalent contribution is from ultrafine particles (UFPs), namely particles with a diameter less than 100 nm. Recent

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interest in UFPs is due to their high deposition fraction (International Commission on Radiological Protection, 1994), large available surface area, potential to translocate to the circulatory system (Weichenthal, 2012) and ability to induce inflammation. The main challenge for the scientific community working in the fields of air quality and epidemiology is to provide an adequate evaluation of the UFP dose–response relationship (Sayes et al., 2007), which is no easy task, since it requires the accurate measurement of personal exposure levels to UFPs.

The most common approach (applied to PM_{10} and $PM_{2.5}$ monitoring from a regulatory point of view) assumes that each person in a given region has the same exposure level, which is often obtained from a few air quality monitors and reflects the mean concentrations in the entire urban area or community (Buonanno et al., 2010; European Parliament and Council of the European Union, 2008). This approach could lead to significant errors in estimating the exposure of an individual to air pollutants, because actual exposure is strongly related to the time–activity patterns of an individual (Buonanno et al., 2011, 2012), followed by their distance from each particle source (Buonanno et al., 2009; Kaur et al., 2005a, 2005b). In fact, several authors have shown that short-term fluctuations in aerosol concentrations increase morbidity and mortality (Brugge et al., 2007; Strak et al., 2010) and therefore, averaging the values of air pollutant concentrations, which can actually hide peak values, may result in unreliable estimates of exposure (Manigrasso and Avino, 2012; Manigrasso et al., 2013). These are fundamental problems which can only be overcome through personal sampling which is able to monitor the particle concentrations to which people are exposed in every micro-environment they visit during a typical day, together with the investigation of people by age, gender, socioeconomic status, activity level or ethnicity. In fact, personal exposure studies provide a detailed foundation for larger scale exposure and public health studies and this level of detail is substantially different from current methods to generate population level exposure estimates based on fixed-site monitoring networks (Steinle et al., 2013). Several studies have already analyzed the relationship between personal exposures and concentrations measured at fixed monitoring stations, showing substantial differences (Avery et al., 2010; Gulliver and Briggs, 2004). Differences between people can be explained by the time activity pattern of the individuals, as well as the environments in which they spend their time. In fact, even people living in the same location can experience different exposure profiles and short-term exposures, which may contribute significantly to daily average exposure.

The aim of the present work was to characterize a couple's daily exposure to UFPs when living in the same house. High temporal resolution data were linked to detailed time activity patterns in order to evaluate the impact of activity patterns on personal exposure. For this purpose, the couples comprised of a man who worked full-time and a woman who was a homemaker, in order to give two groups of people (man and women) with highly different time activity patterns.

2. Materials and methods

2.1. Study design

The measurements were carried out on weekdays in Central Italy (Southern Lazio, in the macro-area of Frosinone) during summer and winter in 2012. A total of 48 participants (24 couples comprising a man who was working full-time and a woman who was a homemaker) were asked to carry a device to measure particle number concentrations and a GPS to record the micro-environments in which they spent their time. In total, 12 of the couples participated in measurements during the summer and winter, respectively, and all of the full-time workers and homemakers were male and female, respectively. We chose couples where the man worked full-time in order to capture certain activities/micro-environments, including transportation, working in an urban office environments and, more generally, environments not encountered by their female partners. The authors point out that the groups were identified by the time activity patterns (home and full-time workers) and not by the gender.

All participants performed their regular activities and the monitored days were representative of their usual weekdays. Furthermore, they were requested to complete a diary in order to record the activities they carried out throughout the day. Only non-smoking couples were included, 10 of which lived in an urban area, eight lived in a suburban zone and six couples lived in a more rural area. A summary of the full-time worker occupations and the couples' house location is provided in Table 1.

2.2. Instrumentation and quality assurance

The mobile experimental apparatus was composed of two hand-held UFP counters (NanoTracer, Philips) equipped with GPS tracking. This device is based on diffusion charging and it is able to measure the number particle concentration in the 10–300 nm size range by means of the current induced by previously charged particles collected on a filter inside a Faraday cage. The NanoTracer can also estimate the different fractions of lung deposited surface area through a semi-empiric algorithm implemented by Marra et al. (2010). The instruments were used in "advance mode", where particle number concentration measurements were performed every 16 s. These personal monitors are equipped with an internal rechargeable lithium-ion battery, which allows them to be used during outdoor trips.

The counters were calibrated at the beginning of the experimental campaign, in order to allow for data quality assurance, by comparison with: i) a Condensation Particle Counter (CPC, TSI Model 3775) to measure particle number concentration; ii) a Nanoparticle Surface Area Monitor (NSAM, TSI Model 3550) to assess the human lung-deposited surface area of particles (reported as $\mu m^2\ cm^{-3}$) corresponding to tracheobronchial (TB) and alveolar (A) regions of the lung; and iii) a Scanning Mobility Particle Sizer (SMPS, TSI Model 3936) spectrometer to measure the mean diameter of the particle number size distributions. The calibration was carried out within a closed volume space (about 16 L), with uniform and stationary particle number concentration. Details are reported in Buonanno et al. (2013b). Quality assurance of the CPC measurements was guaranteed through calibration and flow checks conducted at the start of the monitoring periods. Each CPC was calibrated in the European Accredited Laboratory at the University of Cassino and Southern Lazio by comparison with a TSI 3068B Aerosol Electrometer (Stabile et al., 2013b).

2.3. Methodology description

Each person kept the NanoTracer device on a belt (with the exception of sleeping time when it was placed in the bedroom) for 2 days, carrying it with them in all of the micro-environments where he or

Table 1
Population group characteristics in terms of full-time worker occupation and couples' house location.

Summer time			Winter time		
Couple	Full-time worker	House location	Couple	Full-time worker	House location
1	Factory worker	Urban	13	Employee	Suburban
2	Employee	Urban	14	Employee	Rural
3	Salesman	Suburban	15	Employee	Urban
4	Employee	Urban	16	Salesman	Suburban
5	Odontology	Rural	17	Factory worker	Urban
6	Odontology	Rural	18	Laboratory technician	Rural
7	Employee	Urban	19	Employee	Suburban
8	Policeman	Suburban	20	Medical practitioner	Urban
9	Gym trainer	Rural	21	Engineer	Urban
10	Salesman	Urban	22	Lawyer	Urban
11	Barman	Suburban	23	Professor	Suburban
12	Employee	Suburban	24	Employee	Rural