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Indoor particulate pollution in fitness centres with emphasis on ultrafine particles☆

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ABSTRACT

Fitness centres (FC) represent a unique indoor microenvironment. Exercising on regular basis provides countless health benefits and improves overall well-being, but if these facilities have poor indoor air quality, the respective exercisers might be subjected to some adverse risks. Considering the limited existent data, this work aimed to evaluate particulate pollution (PM_{10}, $PM_{2.5}$, and ultrafine particles – UFP) in indoor air of FC and to estimate the respective risks for occupants (both staff and exercising subjects). Sampling was conducted during 40 consecutive days of May–June 2014 in general fitness areas, studios and classrooms (for group activities) of four different fitness centres (FC1–FC4) situated within Oporto metropolitan area, Portugal. The results showed that across the four FC, PM_{10} ranged between 5 and 1080 $\mu g\ m^{-3}$ with median concentrations (15–43 $\mu g\ m^{-3}$) fulfilling the limit (50 $\mu g\ m^{-3}$) of Portuguese legislation in all FC. $PM_{2.5}$ (medians 5–37 $\mu g\ m^{-3}$; range 5–777 $\mu g\ m^{-3}$) exceeded thresholds of 25 $\mu g\ m^{-3}$ at some FC, indicating potential risks for the respective occupants; naturally ventilated FC exhibited significantly higher PM ranges ($p < 0.05$). Similarly, UFPs (range $0.5–88.6 \times 10^3$ # cm^{-3}) median concentrations were higher (2–3 times) at FC without controlled ventilation systems. UFP were approximately twice higher ($p < 0.05$) during the occupied periods (mean of 9.7×10^3 *vs.* 4.8×10^3 # cm^{-3}) with larger temporal variations of UFP levels observed in general fitness areas than in classrooms and studios. Cardio activities (conducted in studios and classrooms) led to approximately twice the UFPs intakes than other types of exercising. These results indicate that even short-term physical activity (or more specifically its intensity) might strongly influence the daily inhalation dose. Finally, women exhibited 1.2 times higher UFPs intake than men thus suggesting the need for future gender-specific studies assessing UFP exposure.

1. Introduction

The recent estimates have shown that approximately 30% of the worldwide adult population is insufficiently active (Hallal et al., 2012) causing premature mortality (5.3 out of 57 million deaths that occurred worldwide in 2008; Lee et al., 2012) as well as increased risks of various diseases (coronary, heart, type 2 diabetes, breast cancer, colon cancer and etc.; Lee et al., 2012): more than 1.3 million deaths could be averted every year if inactivity was reduced by 25% (Lee et al., 2012). At the same time, overweight and obesity rates have been rising with more than 50% of European adult population (aged ≥ 20 years) being overweight or obese, which annually results in about 320 000 deaths (WHO, 2015). For improved health benefits, World Health Organization (WHO) recommends minimum of 150 min of moderate-intensity of aerobic physical activity per week for adults (WHO, 2016). In order to stay healthy, people frequent fitness centres and gyms. Compared to other indoor spaces (such as offices or homes), these represent a unique indoor microenvironment (Andrade et al., 2017; Revel and Arnesano, 2014) where, due to increased inhalations (from physical activities), occupants might be exposed to higher risks of some relevant indoor pollutants (Alves et al., 2014; Andrade et al., 2017;

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Ramos et al., 2015).

Overwhelming scientific evidence has shown that exposure to ambient particulate matter (PM), namely PM_{10} (aerodynamic diameter < 10 μm) and $PM_{2.5}$ (<2.5 μm) is associated with increased mortality rates, in particular with deaths from cardiovascular and respiratory diseases (Amato et al., 2014; Beelen et al., 2015; Brook et al., 2010; Holgate, 2017). PM is a complex mixture of particles of different sizes including ultrafine particles (UFPs) that are typically designated as those below 100 nm in aerodynamic diameter. UFPs contribute only little to overall PM mass but dominate the number concentrations. Therefore, unlike for PM_{10} or $PM_{2.5}$, the typically used metric is not mass concentrations (μg cm^{-3}) but particle number concentrations (# cm^{-3}) though some studies suggest particle surface area (Kumar et al., 2014; Wichmann et al., 2000). UFPs originate naturally via atmospheric formations (Heal et al., 2012) or from anthropogenic sources (combustion by—-products from power plants, ship and aircrafts exhausts, construction processes, biomass burning, fuel combustion, waste incineration, agriculture processes; Heal et al., 2012), with road traffic being by far the most significant contributor of UFPs in urban areas (Carpentieri et al., 2011; Kumar et al., 2013). Indoors, UFP are emitted from primary indoor sources (Cavaleiro Rufo et al., 2016; He et al., 2004, 2007; Morawska et al., 2013; Kumar et al., 2013; Voliotis et al., 2017) but human activities, such as the use of cleaning products, may result in formation of a wide range of secondary particulates (Rossignol et al., 2013); other studies reported outdoor emissions as the important contributor to indoor number particles (Quang et al., 2013; Tippayawong et al., 2009). Due the higher occupants' density and the lesser degree of dilution or particle dispersion (Hodas et al., 2016; Nazaroff, 2004), exposures to UFPs in indoor spaces might be larger than when outdoors (Bekö et al., 2015b; Mazaheri et al., 2014; Morawska et al., 2013; Reche et al., 2014; Rivas et al., 2014). Inhalation is the major route of human exposure to UFP though dermal exposure cannot be excluded (Mancebo and Wang, 2015). UFPs are highly biologically active (Lee et al., 2014; Terzano et al., 2010) and more toxic and inflammatory than $PM_{2.5}$ (Chen et al., 2016), mostly for two reasons. Firstly, the small size of UFPs allows penetration into the deepest parts of respiratory system (human alveolar macrophages are incapable of removing particles < 70 nm; Bakand et al., 2012) and possibly enter the blood stream (Bakand et al., 2012; Heal et al., 2012). Secondly, due to the larger total surface area (in comparison with PM_{10} or $PM_{2.5}$), UFPs can carry other toxic pollutants (such as heavy metal elements, organic gases) and interact with lung cells (Chen et al., 2016). In view of these aspects, some researchers argued that UFPs might be responsible for the documented adverse health effects of $PM_{2.5}$ (Heinzerling et al., 2016; Terzano et al., 2010). Cardiovascular and pulmonary effects in adult population have been linked with exposure to UFPs but the epidemiologic evidence is far from comprehensive (McCreanor et al., 2007; Heinzerling et al., 2016; Zhang et al., 2009). In addition, UFPs have been linked with increased morbidity (Andersen et al., 2008; Halonen et al., 2008) and respiratory mortality (Chen et al., 2016; Heinzerling et al., 2016).

Overall, the information on indoor air quality in fitness centres is somewhat limited, both in terms of the respective exposures and public health risks. The rather limited data on PM comes from two main types of sport environments: non-educational sport facilities (such as fitness centres and sport halls) and educational settings (such as elementary/primary school gymnasiums or sport facilities from universities). Majority of the studies were conducted in the latter (Alves et al., 2013, 2014; Braniš et al., 2009, 2011; Braniš and Šafránek, 2011; Buonanno et al., 2012a; Castro et al., 2015; Fonseca et., 2014; Kic, 2016; Szoboszlai et al., 2011; Ward et al., 2013; Žitnik et al., 2016), mostly due to the better possibility to control the respective environments during the experiment, whereas only few previous studies have assessed indoor PM in the non-educational sport facilities (Filipe et al., 2013; Saraga et al., 2014; Weinbruch et al., 2012) or fitness centres (Almeida et al., 2016; Ramos et al., 2014; Onchang and Panyakapo, 2016); none of the studies addressed UFPs levels. Furthermore, fitness centres have different purposes from those of school (or university) gymnasiums and competing-sport halls, and thus very specific characteristics (in terms of layout and construction materials, occupants, type of activities, daily patterns or even frequency of operation; Revel and Arnesano, 2014). Therefore, the existing data might not be applicable for the respective exposures in fitness centres. In addition, the wide range of physical activities conducted in the fitness centres and different physicality between both male and female genders will further impact on the respective exposures.

Considering the lack of information mainly in regards with ultrafine particles this work evaluated indoor particulate pollution of fitness centres and estimated the potential risks during exercise activity. Levels of particulate matter (PM_{10} and $PM_{2.5}$) and UFPs in indoor air of four fitness centres were assessed. In addition, the inhalation doses were estimated for the occupants (both staff and exercising subjects) considering different physicality of male and female genders and various scenarios of physical activities (cardio and holistic classes).

2. Material and methods

2.1. Sampling sites description

The sampling was conducted consecutively in four different fitness centres (FC1−FC4) during 40 days (May−June of 2014). All facilities were fitness centers and they were all situated within the Oporto metropolitan area (Portugal). Fitness centers were situated in urban zones where the main air pollution sources were road traffic and industrial emissions (Pereira et al., 2007). FC1 and FC2 were simple and small-size sport facilities. Apart from a fitness area (a combined space for cardiovascular equipment such as treadmills, elliptical, stationary bikes, and for bodybuilding spaces for free weights and machines), these two gyms had only one classroom for group activities. FC3 and FC4 were large fitness centers (~400 up 1000 visitors daily). Apart from a large fitness space, 3 studios for group classrooms for holistic (yoga, pilates, stretching, etc.), aerobic and cardio muscular activities, both these centers had an indoor swimming pool, spas, and beauty/health−care areas. Detailed characterizations of all fitness centers are provided in Table 1, with photographic demonstrations in Fig. 1S.

2.2. Particle collection

In each fitness centre, the sampling was carried out continuously (24 h) during all week days (Mon−Fri) and weekends (Sat−Sun). All equipment was positioned on supports (approximately at 1.4 ± 0.2 m above the floor surface) and at least 1.5 m from walls to minimize the influence on particle dispersion (Holmberg and Li, 1998; Jin et al., 2013) and avoiding all direct emission sources that might interfere with data acquisition (i.e. air conditioners, ventilation points through windows and doors). Necessary measures were taken in order to keep the safety of exercising subjects. One TSI P-Trak™ condensation particle counter (model UPC 8525; TSI Inc., MN, USA) was used for real-time measurement of UFP particle number concentrations (size range N 20−1000 nm; up to 5 × 10^5 particles cm^{-3}) with an intake flow of 0.7 L min^{-1}. Sampler was calibrated prior to the sampling campaign by the manufacturer. To verify its normal operation, the zero readings of the instrument were checked daily (based on the manufacturer