(Ultra) Fine particle concentrations and exposure in different indoor and outdoor microenvironments during physical exercising

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ABSTRACT

Although regular exercise improves overall well-being, increased physical activity results in enhanced breathing which consequently leads to elevated exposure to a variety of air pollutants producing adverse effects. It is well-known that one of these ambient air contaminants is ultrafine particles (UFP). Thus, this study aimed to (1) examine exposure to particle number concentrations (PNC) in size ranging from N20–1000 nm in different sport environments and (2) estimate the respective inhalation doses across varying activity scenarios based upon the World Health Organization recommendations for physical activity. PNC were continuously monitored (TSI P-Trak™ condensation particle counter) outdoors (Out1–Out2) and indoors (Ind1–Ind2; fitness clubs) over 4 weeks. Outdoor PNC (total median 12 563 # cm^{-3}; means of 20 367 # cm^{-3} at Out1 and 7 122 # cm^{-3} at Out2) were approximately 1.6-fold higher than indoors (total median 7 653 # cm^{-3}; means of 11 861 # cm^{-3} at Ind1 and 14 200 # cm^{-3} at Ind2). The lowest doses were inhaled during holistic group classes (7.91×10^{7}–1.87×10^{8} # per kg body weight) whereas exercising with mixed cardio and strength training led to approximately 1.8-fold higher levels. In order to optimize the health benefit of exercises, environmental characteristics of the locations at which physical activities are conducted need to be considered.

KEYWORDS

Air pollution; ultrafine particles (UFP); physical activity; indoor; outdoor

Introduction

Ambient air pollution has been recognized as one of the major threats to human health. Based upon several reports, ambient air pollution was identified among the leading causes of global disease burden (Cohen et al. 2017; GBD 2017; Risk Factor Collaborators 2018), annually resulting in more than 6 million deaths (Landrigan et al. 2018). Further, according to The State of Global Air 2018 report, approximately 95% of the current population resides in cities, in which air pollution exceeded the limits established by World Health Organization (WHO) (Health Effects Institute 2018). Various investigators demonstrated that short-term exposures to "common" air pollutants, such as nitrogen dioxide, ozone, or particulate matter (PM) are associated with increased respiratory hospitalization for obstructive pulmonary diseases, pulmonary infections (Horne et al. 2018; Trnjar et al. 2017). Other disorders attributed to ambient air pollution include increased blood pressure, oxidative stress damage, cardiovascular problems, type 2 diabetes, and elevated mortality rates (Lee, Kim, and Lee 2014; Li et al. 2018; Tsai, Tsai, and C-Y 2018; Yang, Weng, and Chiu 2018). Long-term air pollution exposure might induce cancer increase the risk of premature deaths as well as mortality rate due to cardiovascular disease (Anderson, Thundiyil, and Stolbach 2012). Specifically, fine PM with aerodynamic diameter <2.5 μm; $PM_{2.5}$) has been ranked as the sixth highest risk factor for premature deaths (Health Effects Institute 2018) and chronic exposure to this pollutant alone led to 4.1 million deaths worldwide (Health Effects Institute 2018). In terms of PM, the major attention has shifted towards ultrafine particles (UFP) as these represent a subgroup of PM with aerodynamic diameter below 100 nm. Due to their smaller size, UFP contribute only little to overall PM mass but dominate the number concentrations. In urban areas anthropogenic emissions such as from internal combustion engines, power plants, incinerators, and residential heating emissions (Kumar et al. 2013, 2014) are the major sources of UFP, but may also be formed by natural processes (Heal, Kumar, and Harrison 2012). In confined spaces, activities such as wood and coal burning, cooking, smoking, use of cleaning products, fan heaters, and printers were also identified as relevant sources of UFP (Kumar et al. 2013; Morawska et al. 2013). Due to the lower degree of particle dispersion (Hodas et al. 2016) and higher occupant density, exposures in confined spaces may be especially large (Bekö et al. 2015b; Morawska et al. 2013). UFP are highly biologically active (Lee, Kim, and Lee 2014; Terzano et al. 2010), and due to their small sizes and large surface area, highly chemically reactive. UFP might also transport other toxic pollutants such as heavy metal elements and organic gases and interact with lung cells, which make them more toxic and inflammatory than fine PM (Chen et al. 2016). Nevertheless, current epidemiologic evidence is far from comprehensive (Heinzerling, Hsu, and Yip 2016; Stone et al. 2017; Zhang et al. 2009).

Insufficient physical activity is the fourth common cause of all causes of mortality (Lee et al. 2012; WHO 2009). Globally, one in four adults (and three in four adolescents, aged 11–17 years) is not sufficiently active physically (Hallal et al. 2012; WHO 2018), but due to the changing patterns in transportation and increased use of technology in some countries, levels of inactivity may be as high as 70% (WHO 2018). Lack of physical activity combined with inadequate nutrition or diet might result in a rapid rise in susceptibility to diseases, such as diabetes and obesity, with approximately half of current EU population (≥20 years) considered overweight or obese (WHO 2015). Conducting physical exercises are known to improve health and quality of life with improvements to some of the serious health risks (Saunders et al. 2016). WHO recommendation for physical activity for adults is a minimum of 150 min of aerobic activity per week (moderate intensity) and 300 min per week (approximately 1 hr per day for 5 days per week basis) for additional health benefits (WHO 2016). The positive health effects of exercise have been gaining wide recognition, which drives the popularity of indoor exercising (and a growing number of fitness centers and clubs). Further, many sport and recreational activities, such as walking, running, and cycling are conducted outdoors. However, knowledge regarding the health implications of air quality (outdoors or indoor) during exercise is still largely limited. Although some new studies have been recently published (Andrade and Dominski 2018; Qin et al. 2019), there is only limited information regarding UFP exposure while cycling (Strak et al. 2009; Thai, McKendry, and Brauer 2008; Vinzents et al. 2005). Thus, a critical gap in the understanding required for the development of policies to control and reduce risks of exposure to UFP during physical activity for human health is essential. Thus, the aim of this study was to assess exposure to UFP in different indoor and outdoor environments during physical exercise and to estimate the respective inhalation doses across various sport activity scenarios.

Materials and methods

UFP sampling

Monitoring of UFP during physical exercising was conducted consecutively over 4 weeks (May–June 2015) in Oporto, Portugal and included both outdoor and indoor exposures: at outdoor sites (Out1–Out2) and indoor ones (Ind1–Ind2) that consisted of different-sized and concepts of indoor exercising in fitness clubs. The samplings were undertaken approximately for 1 week at each site and specificities of all the locations and sampling protocols are described in details at Slezakova et al. (2018a, 2018b) with the respective characteristics summarized in Table 1 and Figure S1 (Supplementary Material). Briefly, Out1 is one of the most popular outdoor spots for physical activities in the respective areas situated along the seaside coast and specifically designated for recreational activities such as running lanes with a special surface coating, tap water, and bike rentals. Sport activity exposures assessment at Out2 occurred in the city park whereas indoor exposures to UFP were assessed in different places such as classrooms and studios, and main bodybuilding areas of fitness clubs. Both clubs were situated in urban-traffic zones. Specifically, Ind1 was a simple facility predominantly frequented by the younger individuals located on the ground floor at street level of moderately trafficked streets of a residential building (Table 1). The club was naturally ventilated by

Table 1. Characterisation of selected sites.

	Outdoor	
	Out1	Out2
Location	41° 9⊠ 11.56⊠′ N, 8° 40⊠ 43.62⊠′ W	41° 9⊠ 11.56⊠′ N, 8° 40⊠ 43.62⊠′ W
General description	An urban site with a direct influence of traffic emissions; Situated along sea-side with tools for outdoor exercising (a running line, free drinking-water taps, bike rentals) and outdoor social gatherings (coffees and restaurant esplanades);	Urban–background; Situated in main city public park; Close to major thoroughfares but shielded from direct impacts of traffic emissions due to the presence vegetation (trees, bushes;
Vehicular density (vehicles h^{-1})	906–1842	<3
Exercising subjects (people day^{-1})	1800–2340	1617–3185
	Indoor	
	Ind1	
Location	41° 14⊠ 34.15⊠′N 8° 36⊠ 41.60⊠′W	
General description	In residential area (urban site influenced by traffic emissions) Simple-concept club with 1 bodybuilding area (a joint space for bodybuilding machines and cardiovascular equipment) and 1 studio (for group activities)	
Cleaning and maintenance schedule	During lunch hours (13:00–14:00) and sporadically when closed (after 23:00)	
Indoor ventilation	Natural (windows opening); mechanical ventilation system in construction	
Exercising subjects (people day^{-1})	84–251	
	Bodybuilding area	Studio
Room volume (m^3)	402	144
Construction:	Brick, concrete, cork, glass	Brick, concrete, paint, cork, glass
Ceilings	Paint	Paint
Flooring	PVC, rubber	Rubber
Wall	Paint, cork, mirrors	Paint, cork, mirrors
	Ind2	
Location	41° 10⊠ 48.32⊠′ N 8° 39⊠ 17.90⊠′ W	
General description	Large shopping centre (on 2nd floor) Internationally-established branch with a bodybuilding area, 3 studios (group classes), spa facilities (physical therapy & cosmetic treatments), swimming pool	
Cleaning and maintenance schedule	Main cleaning during off-hours (before opening and after closing); Continuously throughout the day when needed with studio spaces cleaned after each class	
Ventilation	Mechanical controlled ventilation with centrifugal fan and air conditioning with in/out pipe machines;	
Exercising subjects (people day^{-1})	up to 1000	
	Body building area	Studios
Room volume (m^3)	2504	~232
Construction:	Brick, concrete, wood, glass, aluminum	Concrete, wood, glass, aluminum
Ceilings	Uncovered with ventilation system pipes exposed	Paint and ventilation system pipes exposed
Flooring	PVC	Wood
Wall	Paint, mirrors	Paint, mirrors, (panel between the studios)

opening windows throughout the day, with all rooms facing the main street. It had only one classroom for group activities and one bodybuilding area, which was a space, with both free weights and machines and cardiovascular equipment including stationary bikes and treadmills. Ind2 was a club that was part of the internationally established branch situated on the upper level in a shopping mall, and apart from the large bodybuilding area, it had three studios (for group classes), swimming pool, and spa facilities. During the working hours (7:00–23:00), ventilation was provided by a central mechanical system operated by a centrifugal fan and air conditioning.

UFP measurements (size range N20–1000 nm) were conducted continuously with TSI *P*-Trak™ condensation particle counters (model UPC 8525; TSI Inc., MN, USA) with logging intervals of 1 min and sampling flow of 0.7 L/min. Calibration procedures were undertaken prior to monitoring by the manufacturer. In order to minimize the zero drift effect, all equipment was checked regularly using the external zeroing module. Further detailed information relevant to sampling was recorded daily including meteorological parameters, exercising subjects, and type of activity as summarized in Table 1 and Table S1 (Supplementary Material).

UFP inhalation dose calculations

Analysis of the potential risks of subjects associated with inhalation exposure to particles while conducting physical activities was based upon estimated doses at different sites. Bearing this in mind exposure occurred when a subject was in contact with an ambient pollutant, whereas dose occurs only when particle traversed the physical boundaries of a subject. Inhalation doses to UFP during conducting physical activities was calculated as (1):

$$D = (IR/BW) \times c \times t \qquad (1)$$

where D is the age-specific UFP dose (# per kg body weight); IR and BW are age-specific inhalation rate (L/min) and human body weight (kg), respectively; c represents the UFP number concentration (# cm^{-3}); and t is the exposure time (min). This deterministic approach is a simple and standardized model (Pandey, Kumar, and Devott 2005) that enables a point estimate of exposure. In contrast to probabilistic methods, it is easier to carry out and produce straight-forwarded results. The analysis was age-specific, and grouped the subjects into three categories, namely with adults 21 to <31 years old; 31 to <41; and 41 to <51. Further, the dose for different age categories on the basis of environment-specific concentrations and under different activity scenarios was estimated. Since the main objective of this investigation was to estimate the dose of a "typical individual" in a population (corresponding to 50^{th} percentile of exposure/dose), median UFP concentrations were employed for different age groups of every environment. Some details of this approach are also described elsewhere (Fonseca et al. 2014; Slezakova et al. 2018a). The different activity scenarios included as follows: i) recreational/cardiovascular high-intensity (namely running, and cycling) and medium-intensity (power walking) conducted both outdoors and indoors (on treadmills and stationary bikes) with a duration time of 60 min; ii) indoor groups activity classes included holistic concepts (i.e. yoga, Pilates, Thai-chi) and were conducted in studios of fitness centers (duration 50 min); iii) indoor group mixed classes that included cardio exercising and strength and endurance training (i.e. concepts such as body pump, circuit training; duration 50 min); and iv) individual bodybuilding workout (60 min conducted in the bodybuilding areas) as presented in Table S2. For outdoor exposure, the time duration was based upon WHO recommendations for additional benefits (300 min per week (approximately 60 min per day) for the additional health benefits; WHO 2016). For indoor exercising, durations of classes conducted in the respective clubs were used. In the final step, each type of this scenario/exposure was characterized in terms of the physical intensity with the respective IR (mixed populations) with age – (21 to <31 years; 31 to <41; and 41 to <51) specific factors retrieved from US EPA (2011). All adapted physical parameters (body weights, inhalation rates) were estimated for mixed populations both men and women. An example of the inhalation exposure assessment is demonstrated in Table S3 (Supplementary Material).

Statistical analysis

The statistical data treatment was performed using the Microsoft Excel 2013 (Microsoft Corporation), SPSS (IBM SPSS Statistics 20) and Statistica software (v. 7, StatSoft Inc., USA). Because the obtained data did not display normal distributions (Figure S2) as established by Shapiro–Wilk's test, nonparametric Mann–Whitney U test was used for the comparison of the obtained medians. The statistical significance was set at $p < .05$.

Results

Population of the study and conducted activities

During the outdoor exposure assessment, the number of exercising subjects ranged between 12 and 882 subjects/hr at site Out1 and 44–574 at

Out2, with medians of 206 and 186 subjects/hr, respectively. The outdoor exercising was conducted with 1.5–3-fold higher population number than indoor (Table 1), as at Ind1 and Ind2 the means were, respectively, 3–35 and 23–105 individuals/hr (i.e. medians of 191–265 and up to 1200 subjects per day). The number of exercising subjects changed throughout the days (Figure 1). Outdoor activities were conducted predominantly during the mornings (9–10 a.m.) and post-labor hr (6–7 p.m.), whereas the major peaks for indoor exercising occurred during lunch hours (11–12 a.m.) and in the evening hours (8–9 p.m.).

The types of physical activities (Figure 2) also differed between the sites. At Out1 the majority of subjects conducted running (40%) followed by cycling (37%), whereas 17% of the exercising population did power walking; other activities such as roller-skating and slide scooters accounted for 6%. At SO2, 47% exercising subjects conducted walking or power walking, whereas it was 31 and 20% for running and cycling, respectively, recreational activities were conducted by 2%. In clubs, the subjects conducted more diverse activities and group classes based on the available modalities present at the clubs. Biking, treadmill walking or running were always performed in cardio zones that were part of the main bodybuilding areas. Further, on daily basis, it was observed that the majority of exercising populations were at bodybuilding areas (conducting trainings); group activities were conducted by 2–49% of the training individuals based upon the given schedules and room capacities.

UFP levels

The levels of UFP during exposure assessments at four locations are summarized in Figure 3. UFP number concentrations during outdoor exposures were approximately 1.6-fold higher than indoors. The median concentration across all outdoor sites was 12 563 cm^{-3} (means of 20 367 # cm^{-3} and 7 122 # cm^{-3} at Out1 and Out2, respectively) whereas it was 7 653 # cm^{-3} when exercising indoors (means of 11 861 # cm^{-3} at Ind1 and 14 200 # cm^{-3} at Ind2). The obtained medians as well as the respective distributions of UFP varied significantly between different environments (indoor *vs*. outdoor) as well as between each site. The lowest median UFP (5 575 # cm^{-3})

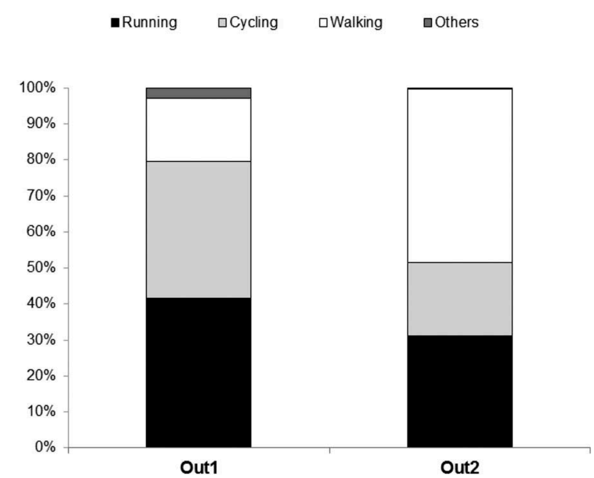

Figure 2. Physical activities during the outdoor (Out1–Out2) exposure assessments to particle number concentrations.

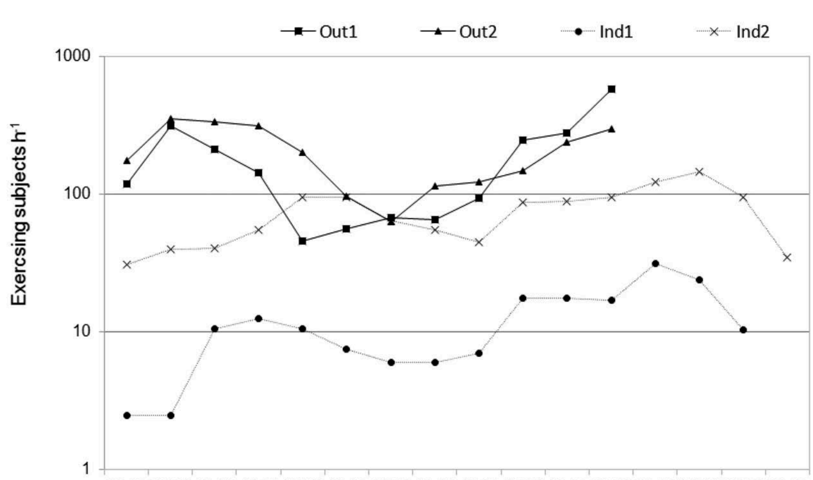

Figure 1. Daily average profiles of exercising subjects during the outdoor (Out1–Out2) and indoor (Ind1–Ind2) exposure assessments.

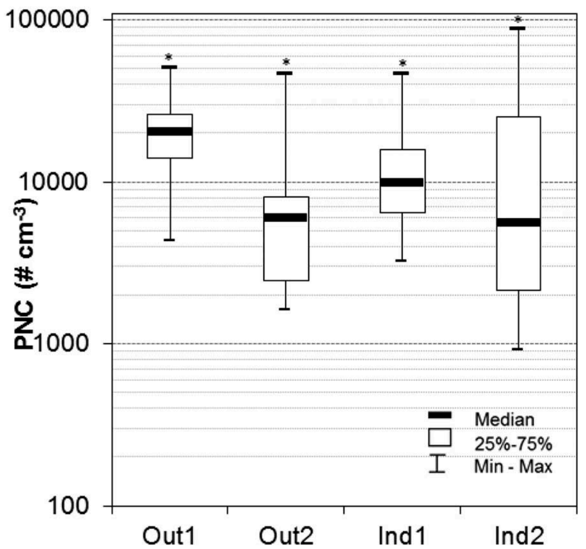

Figure 3. Particle number concentrations (PNC) (▬ median; ☐ 25–75%, and range) during outdoor (Out1–Out2) and indoor (Ind1–Ind2) physical activity exposure assessments. Note: *Represents significantly different ($p < .05$) medians and distributions of PNC.

was detected at Ind2 even though this site was a larger facility visited per day by approximately five times more clients. Ind2 was equipped with mechanical ventilation, which led to approximate twofold lower UFP levels than at Ind1 (naturally ventilated).

UFP dose inhalation

The inhalation doses associated with exposures to UFP during different physical activity scenarios such as running and cycling, and power walking conducted outdoors and indoors are presented in Figure 4a. The inhalation doses due to these activities ranged between 1.86×10^8–7.65×10^8 # kg^{-1} for running and cycling, and between 4.56×10^7–1.87×10^8 # kg^{-1} for power walking. The highest doses of UFP were associated with exposures at Out1 (approximate 3.6–3.9-fold higher). High-intensity activity (running and cycling) resulted in 4–4.2-fold increase in inhaled UFP. Specifically for indoor exercising, and considering different concepts (Figure 4b), the lowest UFP doses were inhaled during holistic group classes (range of 7.91×10^7–1.87×10^8 # kg^{-1}), whereas exposure during activities, that combined

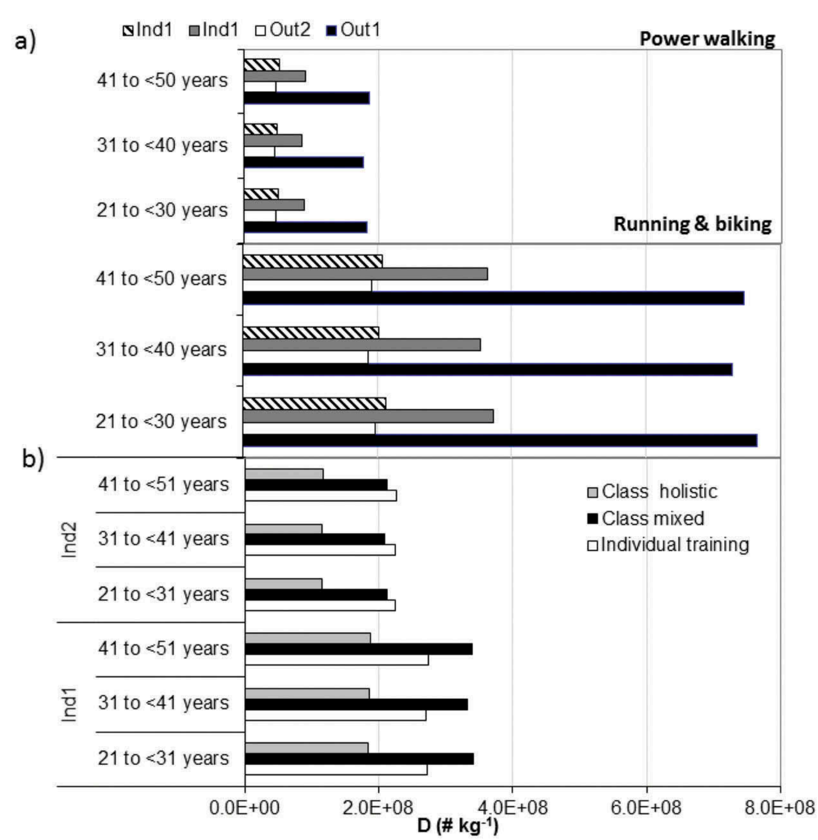

Figure 4. Estimated inhaled dose of particle number concentrations (PNC) for population of mixed subjects during various physical exercises: (a) running & cycling, and power walking; (b) different concepts of indoor exercising.

a mix of cardio and strength training, resulted in approximately 1.8-fold higher dosage. Finally, for the individual body workouts, the inhalation dose of UFP was 1.05×10^7–2.73×10^8 # kg^{-1}.

Discussion

Since society currently spends most of its time indoors, the relevance of healthy confined space environments has been highlighted both by environmentally concerned organizations and by regulatory policy directives and guidelines. Because of the prolonged time, indoor air pollution might significantly enhance adverse risks to human health (WHO 2010); with respective exposures several magnitudes higher than those outdoors (Buonanno et al. 2012). Thus, current research has focused on various indoor locations, where individuals reside, travel, work, or study, such as homes, offices and schools, modes of transportation, and restaurants (Bekö et al. 2013, 2015a; Oliveira et al. 2019; Slezakova, Alvim-Ferraz, and Pereira 2012, 2014;Slezakova, de Oliveira Fernandes, and Pereira 2019; Stacey 2019; Wells et al. 2015). However, the environments to conduct physical activities have a specific purpose and current knowledge on exposure impacts on health during exercising is limited. The increasing focus on indoor air quality (IAQ) in schools (Annesi-Maesano et al. 2013; Rufo et al. 2015) resulted in several investigations conducted in school gymnasiums (primary, secondary or university) (Alves et al. 2014; Buonanno et al. 2012; Castro et al. 2015; Fonseca et al. 2014; Kic 2016; Žitnik et al. 2016).

Fitness centers serve a different purpose and thus exhibit different structural organizations and characteristics in terms of construction materials, maintenance, ventilations, size, and space of the facility. In a recent systematic review dedicated to environments for physical exercise and sport practice being noneducatory spaces, Andrade and Dominski (2018) identified 20 studies that provided information on indoor air pollutants, with carbon monoxide (CO) and nitrogen dioxide (NO_2) the most studied pollutants. Further, whereas Andrade and Dominski (2018) indicated some less commonly studied pollutants in noneducatory environments for physical exercises, such as benzene, toluene, ethylbenzene and xylene (BTEX), and non-methane hydrocarbons (NMHC), information regarding UFP in these places does not apparently exist. Upon closer evaluation, one of the studies on IAQ in sport environments assessed the distribution of PM and thus some information regarding particle number concentrations (PNC) are available. Assessing four indoor climbing-wall centers in Germany (cities of Munchen-Thalkirchen, Stuttgart, Hanau, and Regensburg), Weinbruch et al. (2012) reported number concentration (particle size range of 3.7 nm–10 μm) of 3.3–27.5×10^3 # cm^{-3} during high occupancy periods. The use of chalk, and its impacts while exercising, was also demonstrated in a study from Spain (a university gymnasium), where investigators reported increased PNC (size range of 100 nm–10 μm) of 600 ± 160 # cm^{-3} when using chalk and 490–590 # cm^{-3} without its utilization (Alves et al. 2014; Castro et al. 2015). While these levels (Figure 3) and scenarios exposure varies from those of this study, a more insightful comparison is rather difficult to provide in view of different study protocols.

Recreational activities, such as jogging, cycling, walking, or skating are often undertaken outdoors with some studies showing positive benefits of outdoor exercising, that include reduction of depression and perceived stress compared with physical activities conducted indoors (Roe and Aspinall 2011). However, physical activity requires a healthy air quality. Conducting outdoor exercising on a regular basis in places with highly polluted air might lead to rather harmful consequences instead of positive health outcomes (Bos et al. 2014; Lovinsky-Desir et al. 2016; Tainio et al. 2016). In an attempt to better understand the associations of air pollution and exercise on human health, Qin et al. (2019) recently synthesized the available scientific evidence (1990–2017). Based on previously published 25 studies, Qin et al. (2019) concluded that exercising in a polluted air environment was correlated with improved peak expiratory flow (PEF) but not with other health indicators. Further, a combined effect of air pollution and exercising was linked with an elevated risk of abnormal cardiopulmonary function, immune dysfunction, and diminished exercise performance (Qin et al. 2019). Nevertheless, once again air pollutants included in the review were traditional contaminants, CO, NO_2, sulfur dioxide (SO_2), ozone (O_3), and PM; data for UFP exposure during the physical activities are not yet available. The results in

Figure 3 demonstrated that the highest UFP levels were obtained during the exposure assessment at Out1, most likely due to high traffic density in the surroundings of the site (Table 1). Clearly, spatial variation (*i.e.* location) to conduct physical exercising is relevant for the respective exposures; UFP levels at SO2 were approximately threefold lower than at Out1 though both sites were approximately just 1500 m apart (Table 1). Therefore, individuals need to consider the respective site locations and, when possible, exercise away from traffic. In addition, temporal variations such as meteorological conditions and seasonal trends are relevant for UFP exposure (Morawska et al. 2008) and therefore long-term assessments need to be included in future studies.

Due to the lack of regulatory limits or guideline recommendations on UFP in outdoor or indoor air, it is rather difficult to interpret the obtained levels. Up to this date, probably the most comprehensive work on an international scale was conducted by Morawska et al. (2008) who summarized all available studies reporting UFP concentrations in ambient air and assessed these based upon site specificity and characteristics (ranking from clean background to tunnels; Table S4). For urban-background sites, Morawska et al. (2008) estimated the mean value of 7.3×10^3 # cm^{-3} whereas for urban sites it was 10.8×10^3 # cm^{-3}. Clearly, whilst UFP levels during physical activities at SO2 (urban-background) were within the indicated levels, UFP pollution at Out1were approximately twofold higher, thus indicating strong impacts of traffic emissions at this site. In addition, meteorological conditions are relevant for the formation of atmospheric particles. In regard to wind speed (Table S1), at both Out1 and Out2, particle number concentrations (PNC) were significantly and inversely correlated with wind speed, possibly due to a greater degree of atmospheric dispersion with stronger winds (Shi et al. 2007). However, the respective associations were relatively low. At the same time, due to the existence of a running lane, Out1 was the most highly frequented place (up to 882 individuals/hr) to conduct sport activities with the majority (40%) of the exercising population undertaking running, during which elevated inhalation rates might lead to increased exposure to ambient air pollutants and thus blocking the positive benefits of exercise. In this regard, Pasqua et al. (2018) estimated that aerobic activity with elevated inhalation rate conducted in the cleanest cities based on the WHO data led to improved health (throughout up to 90 min). Whereas exercising in the polluted atmospheres generated higher inhaled doses of pollutants (37–66-fold higher for PM_{10} and $PM_{2.5}$), which abolished the health benefits provided by exercise. There were no further health benefits after 15 min of physical activity if conducted in the polluted atmosphere and air pollution risks surpassed the health benefits of those of exercising after 75 min of the activity. In agreement with those results, the highest exposure to UFP was associated with intense aerobic activities (i.e. running and cycling; Figure 4a) with the highest dose obtained outdoors at Out1, which was the most polluted site in terms of UFPs. In addition, in this study high inhalation rate associated with the intense or moderate activities was the predominant parameter for the observed differences of the estimated UFP doses (up to 76%) in view of the similarity of body weight among the considered population groups (Table S2) and considering the obtained UFP levels at four sites. It is worthwhile noting that, when exercising indoors (at Ind1), UFP exposures were still approximately twofold higher than when exercising in the city park (i.e. Out2). The facilities of fitness club Ind1 were not equipped with mechanical ventilations, and clean air was provided by windows opening which might consequently lead to infiltrations and accumulation of ambient emissions to indoors (the club is situated in an urban-traffic site). It is apparent that ventilation is a key parameter for particle infiltrations (Nazaroff 2004). Nevertheless, air exchange rates could not be measured in this study, thus preventing a direct assessment of particle infiltrations. However, the obtained results were in general agreement as naturally ventilated indoor environments of Ind1 exhibited significantly higher particle number than those with controlled ventilation system of Ind2. Specifically then considering indoor activities (Figure 4b), across the three age categories, the highest exposures occurred during the group classes with mixed cardio/strength activities. The ratio of inhaled UFPs during mixed and holistic classes was between 1.79 (31 to <41 years) and 1.85 (21 to <31 years), whereas for individual bodybuilding training, the respective ratios were approximately 35% lower (1.18–1.25). This might be attributed to durations of individual training (60 *vs.* 50 min for group activity) as well as the type of performed activities; bodybuilding training included both aerobic activities (i.e. warm-up at beginning of sessions with high-intensity inhalation rate, and moderate inhalation during the workouts). Finally, it should be noted that across all age categories and activity scenarios, the inhalation exposures at Ind2 were approximately 1.5–1.6-fold lower than at Ind1. This club, while being the most frequented, provided the lowest indoor exposures due to its advanced ventilation system and strict maintenance and cleaning protocols in its areas. It should be pointed out that this investigation presents an initial approach to assess particle exposure while exercising in the respective metropolitan areas. The method was based upon a simple approach and enabled straightforward results (i.e. median dose corresponding to 50^{th} percentile exposure/dose) using physiologic parameters with values provided by USEPA (2011). However, gender and age-specific values established specifically for the Portuguese population might allow for deeper simulations including more complex probabilistic exposures (population-related approaches). Further, the size distribution of the measured fraction was not obtained within this study. The information regarding the respective distributions may be relevant to better assess the particle deposition within the human respiratory system (Hussein et al. 2013; Koivisto et al. 2014, 2018) and provide a more comprehensive analysis of the obtained findings.

Overall, data demonstrated that a simple answer to whether exercising indoors or outdoors is more beneficial to human health might not be available, as among other parameters, air quality, whether it is ambient one or in confined spaces, varies highly. However, it might be relevant that future guidelines on exercise consider the environmental characteristics of the sites at which physical activities are conducted, emphasizing the potential adverse impacts of air pollutants whether indoors or outdoors in order to optimize the health benefits and minimize the possible adverse health risks.

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