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Particulate matter in ambient air and its association with alterations in lung functions and respiratory health problems among outdoor exercisers in National Capital Region, India

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ABSTRACT

Regular exercise improves physiological processes and yields positive health outcomes. However, it is relatively less known that exposure to air pollution during outdoor exercises may actually exacerbate several health problems. The present cross–sectional study was undertaken to assess the particulate matter (PM) in the ambient air and its association with lung functions, pulse rate and respiratory problems among 378 outdoor exercisers in the National Capital Region (NCR), India. Lung functions were measured using a Spirometer (PIKO–1, PIKO–6) and respiratory problems were recorded through a questionnaire–based survey. Concentrations of particulate matter smaller than 2.5 and 1 microns were monitored at 10 locations across the study area using an online automated ambient air monitoring instrument–HAZ–DUST (EPAM–5000). Decline in Forced Expiratory Volume in 1 sec–FEV_1 (p<0.001) and Peak Expiratory Flow Rate–PEFR (p<0.001) was observed among the outdoor exercisers compared to the Indian reference values. Ambient air monitoring showed higher $PM_{2.5}$ concentrations at all the study locations compared to the recommended permissible levels for residential areas in India. Risk of FEV_1 (%) predicted cases with <80% showed an increase from 2.32% to 8.69% among the exercisers with respect to PM_1 concentration from lower to higher limit at the study locations. Similarly, PEFR showed an increased risk of predicted cases <80% from 0.78% to 2.91% among outside exercisers for lower to higher limit of PM_1 concentration. Cases with FEV_1 predicted <80% increased from 2.56% to 13.98% and for PEFR from 0.96% to 5.24% among outdoor exercisers for the corresponding lower to higher limits of $PM_{2.5}$ concentrations. The study demonstrates that outdoor exercisers in locations with high PM concentrations are at a risk of lung function impairment. These impairments are due to deposition of PM in the smaller and larger airways.

Keywords: *Particulate matter, outdoor exercisers, respiratory health*

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1. Introduction

Millions of people daily walk or run on streets or parks as a part of their routine exercise. Regular exercise is known to improve physiological processes and is considered key to good health. However, exposure to air pollution may cause a negative impact on health (Giles and Koehle, 2014). Data collected globally during 2002–2010 to track air pollution trends in 189 megacities indicated that Indian cities are among the most polluted ones (Alpert et al., 2012). The contention between need for routine exercise and exposure to high levels of airborne pollutants presents an interesting challenge of balancing benefits against detriments, particularly in areas of poor to very poor air quality (Giles and Koehle, 2014). There is good evidence of the effects of short–term exposure to PM_{10} on respiratory health, but for mortality, and especially as a consequence of long–term exposure, $PM_{2.5}$ is a stronger risk factor than the coarse fraction of PM_{10} (WHO Regional Office for Europe, 2013). All–cause daily mortality is estimated to increase by 0.2–0.6% per 10 $\mu g/m^3$ of PM_{10} (WHO Regional Office for Europe, 2006; Samoli et al., 2008). Long–term exposure to $PM_{2.5}$ is associated with an increase in the long–term risk of cardiopulmonary mortality by 6–13% per 10 $\mu g/m^3$ of $PM_{2.5}$ (Pope et al., 2002; Beelen et al., 2008; Krewski et al., 2009).

Physical inactivity poses a significant health risk to individuals as it increases the likelihood of developing heart disease, type 2 diabetes mellitus, cancer, and stroke (Blair, 2009; Williams, 2009). It is estimated that physical inactivity is the fourth most common cause of mortality in humans and contributes to 3.2 million annual deaths (WHO, 2009). Regular physical activities of moderate intensity like brisk walking can decrease the risk of non–communicable diseases (Willet et al., 2006). However, many of the most accessible forms of exercise, such as walking, cycling, and running often occur outdoors (Giles and Koehle, 2014). In many modern societies, jogging has become increasingly popular (Aydin et al., 2014). In India, outdoor exercises like walking, jogging and cycling are undertaken by several citizens during the morning and evening hours. Susceptible groups with pre–existing lung or heart disease, as well as elderly people and children, are particularly vulnerable to PM effects (WHO Regional Office for Europe, 2013).

A recent study conducted in Central India shows that the annual mean $PM_{2.5}$ concentration is three times higher than the National Ambient Air Quality Standards of India (NAAQS) (Deshmukh et al., 2013a). Similar higher concentration was also observed in the National Capital Region (NCR), India (Kesavachandran et al., 2013). There is no evidence of a safe level of exposure or a threshold below which no adverse health effects occur (WHO Regional Office for Europe, 2013). Also, higher concentrations of PM_1, $PM_{2.5}$ and $PM_{2.5–10}$ were found during winter in Central India due to enormous biomass burning, especially during the night time (Deshmukh et al., 2013a). This was suggested to be associated with the use of combustible goods like fire wood and dung cake and temperature inversion in the open space by the local people to keep them warm. Lower concentrations were observed during monsoon due to high precipitation (Deshmukh et al., 2010; Deshmukh et al., 2013a).

In another study, higher nasal resistance was observed among outdoor runners during the times of heavy traffic as compared to runners at locations away from the traffic (Aydin et al., 2014). PM exposure can lead to oxidative stress, increased bronchial responsiveness, increased airway resistance, and increased number of airway inflammatory cells, each of which may impair lung function (Holgate et al., 2003; Kelly, 2003). The assumption that the high PM concentrations in the atmosphere can put outdoor exercisers at high risk of lung ailments prompted us to take up this study. The present cross–sectional study aims at correlating the relationship between PM in the ambient air and its association with lung functions, pulse rate and respiratory problems among outdoor exercisers in the National Capital Region (NCR), India. To the best of our knowledge, this is the first report on the association between PM concentration and respiratory health risks among outside exercisers in India.

2. Materials and Methods

2.1. Study design, study subjects, and the study location

A cross–sectional study was conducted among 378 residents who regularly exercise outdoors (i.e., walking, running etc.) and 163 matched non–exercisers who do not do any outdoor exercise. Both the groups lived in the National Capital Region, India. National Capital Region (NCR) includes areas at the outskirts of New Delhi and can be considered as a semi–urbanized part of the megacity of Delhi. Ten study locations were randomly identified from two regions of NCR, namely NOIDA (Figure 1) and Gurgaon (Figure 2). The main sources of pollution in these areas are the large–scale infrastructural development activities like construction of roads and houses, moderate traffic, and agricultural dust. A respiratory health survey was conducted through a questionnaire to assess the lung–related problems experienced by the study subjects. All the subjects participating in the study worked and resided within 3 km of the air quality sampling site. This approach ensured that the air quality levels represented the actual exposure to PM for the participants. Also, the study subjects conducted outdoor exercises within this 3 km radius of the sampling sites. Those subjects taking any medications were excluded from the study. The study participants were agricultural laborers, anganwadi (child care) workers, beauty parlor workers, haircutting saloon workers, small business proprietors, shop owners and salesmen, contract manual laborers, dairy and livestock workers, gardeners, health care workers, housewives, teachers, and students.

2.2. Ambient air monitoring for particulate matter

Air monitoring for PM concentrations ($PM_{2.5}$, PM_1) was conducted at each of the 10 study location for 8 h per day. For ideal correlation, the day of the monitoring and the day of the health survey were kept the same. Air monitoring was done using an online automated ambient air monitoring instrument, HAZ–DUST (EPAM–5000, Environmental Devices Corporation, USA) at the study sites. The HAZ–DUST EPAM–5000 is a portable microprocessor–based particulate monitor using the light scattering method suitable for ambient air quality investigations. Interchangeable size–selective impactors monitor $PM_{2.5}$ and $PM_{1.0}$. The performance profile of the instrument includes sensing range (0.001 to 20 mg/m^3), particle size range (0.1 to 100 µm) and sampling flow rate of 1–4 L/min. Ambient air monitoring was selected at a height of 10 m from the ground and placed on the roof of nearby houses, which were about 200 m away from traffic intersections. Sampling sites for PM measurements in ambient air were selected on a random basis at the study locations.

Quality assurance/quality control procedures were maintained according to the instruction manual of the instrument. Manual–zero sets the measurement baseline of the instrument to zero mg/m^3. The manual–zero check was performed prior to beginning a new set of measurements. Flow meter was used to ensure the flow rate of 4 L/min before each sampling procedure. The same monitor was used at all the locations. The study was conducted during the months of July to September between 2008 and 2010.

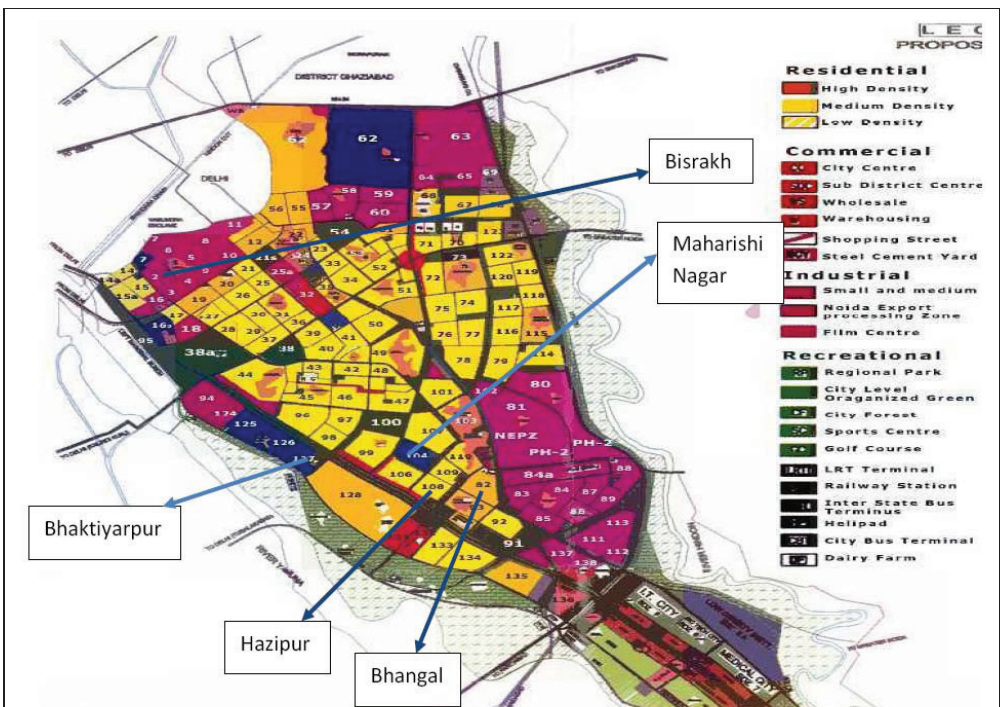

Figure 1. *Study locations at NCR region–NOIDA.*

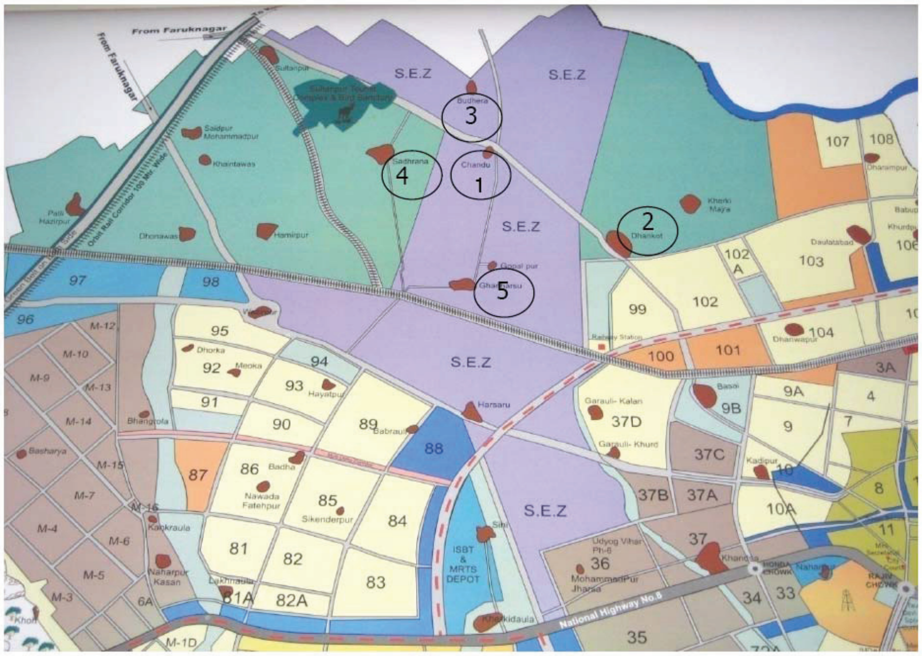

Figure 2. *Study locations at NCR region–Gurgaon (1=Chandu, 2=Dhankot, 3=Budhera, 4=Sadhrana, 5=Ghari).*

2.3. Spirometry, pulse rate and respiratory health status

Peak expiratory flow rate (PEFR) and forced expiratory volume in the first second (FEV_1) were measured using a battery–operated dry spirometer (PIKO, UK) as per the recommendations of the American Thoracic Society standards. The best values for PEFR and FEV_1 from three tests for each subject were recorded. The interpretation of lung function was carried out using the predicted reference equations for Indians (Udwadia et al., 1986). The lung function test was conducted among study subjects during morning hours after their exercise. Pulse (heartbeats/minute) was measured at the wrist by placing the index and middle finger over the underside of the wrist below the base of the thumb and measurement was done for one minute. The study also assessed the self–reported respiratory illnesses of the surveyed volunteers and recorded the same through a questionnaire. Both the questionnaire–based survey and ambient air monitoring were conducted on the same day. Subjects were screened by an initial questionnaire to identify outdoor exercisers using the following question: "Are you regularly doing any outdoor physical activity or exercises in the morning for the last three years for minimum 45 minutes?" If the subject's answer was "yes", then they were considered as outdoor exercisers and included in the analysis. Those who responded "no" were considered as non–exercisers and treated as the control group for this study. This study is a part of a health survey conducted among the residents of the National Capital Region funded by the CSIR Network program from 2007–2012. Clearance was obtained from the Institutional Human Ethical Committee before starting the study.

2.4. Statistical analysis

Student's *t*–test was used to compare the mean values of age, height, weight, Body Mass Index (BMI), body fat (%) FEV_1, PEFR and pulse rate among the test and control groups. The odds ratio and 95% CI for FEV_1 (%) predicted and PEFR (%) predicted values adjusted for age, height and smoking status between exercisers and non–exercisers was done using multivariate analysis. Chi–square test was used to test the significance of respiratory symptoms between the study groups. Regression model was used to predict the trend of lung functions with higher or lower concentration of PM in the ambient air with FEV_1 and PEFR as the dependant variables and PM concentration as the independent variable. The criterion of significance was set at $p<0.01$. All the calculations were performed after adjusting for smoking status to exclude the confounding effect of smoking in the analysis. Statistical analysis was done using STATA IC 13 software package and Microsoft Excel 2007.

3. Results

Physical characteristics, pulse rate and lung functions of the study subjects are shown in Table 1. No significant difference was observed for age and height between outdoor exercisers and the non–exercise control group, though a significant difference was observed in their mean weight ($p<0.01$), Body Mass Index ($p<0.01$) and body fat (%) ($p<0.001$). The study subjects in both groups were in the category of lower middle class socioeconomic status according to the modified criteria of socioeconomic status in India (Bairwa et al., 2012). Lung function status i.e., FEV_1 and PEFR of the subjects was shown in Table 1. Decline in FEV_1 ($p<0.001$) and PEFR ($p<0.001$) was observed among non–exercisers as compared to outdoor exercisers (Table 1). Even though pulse rate was higher among outdoor exercisers compared to non–exercisers, the values are within the normal range in both groups. Reference values predicted for normal healthy non–smokers are generally used in epidemiological studies as well as during clinical surveillance exercises to determine low lung function and assess the effect of environmental exposure (Falaschetti et al., 2004). The observed mean FEV_1 and PEFR values among outside exercisers and non–exercisers were lower than the reference values predicted for Indian population.

Ambient air monitoring showed higher $PM_{2.5}$ concentration at all study locations compared to the recommended permissible levels for residential areas in India (Table 2). No significant difference in the respiratory symptoms was observed between both the study groups (Table 3). Risk of FEV_1 (%) predicted cases with <80% showed an increase from 2.32% to 8.69% among exercisers with respect to PM_1 concentration from lower to higher limits at the study locations. Similarly, PEFR showed a corresponding risk of predicted cases <80% from 0.78% to 2.91% among outdoor exercisers for lower to higher limit of PM_1 concentration (Table 4). Cases with FEV_1 predicted <80% increased from 2.56% to 13.98% and for PEFR from 0.96% to 5.24% among outdoor exercisers for corresponding lower to higher limits of $PM_{2.5}$ concentrations at the study locations (Table 5). Interestingly, correlation studies revealed an insignificant relationship (p>0.05) between increase in mean PM concentration (<2.5 micron, <1 micron) and lower lung functions (FEV_1 and PEFR) among outdoor exercisers and non–exercisers (Figures 3 and 4).

4. Discussion

To the best of our knowledge, this is the first evidence–based report on the respiratory health status of outdoor exercisers in India, especially under poor ambient air conditions. The study locations are listed as sensitive and critical air pollution sites in India by the Central Pollution Control Board, India (Times of India, 2014). The outdoor exercisers and non–exercisers showed a risk of reduced FEV_1 and PEFR compared to their predicted Indian norms. A gradual fall in FEV_1 and PEFR was also associated with an increase in PM_1, $PM_{2.5}$ concentrations. All these evidences indicate the impairment of lung function parameters among outdoor exercisers due to exposure to PM. Similar observation of higher PM concentrations in ambient air and decline in lung function among outdoor exercisers was reported in a recent review (Giles and Koehle, 2014). Smaller particles with an aerodynamic diameter of about 0.003 to 5 µm are deposited in the trachea–bronchial and alveolar regions by deposition (CCOHS, 2012). Hence, the decline in FEV_1 and PEFR among study subjects can be associated with the deposition of particles <2.5 µm in the trachea–bronchial and alveolar regions.

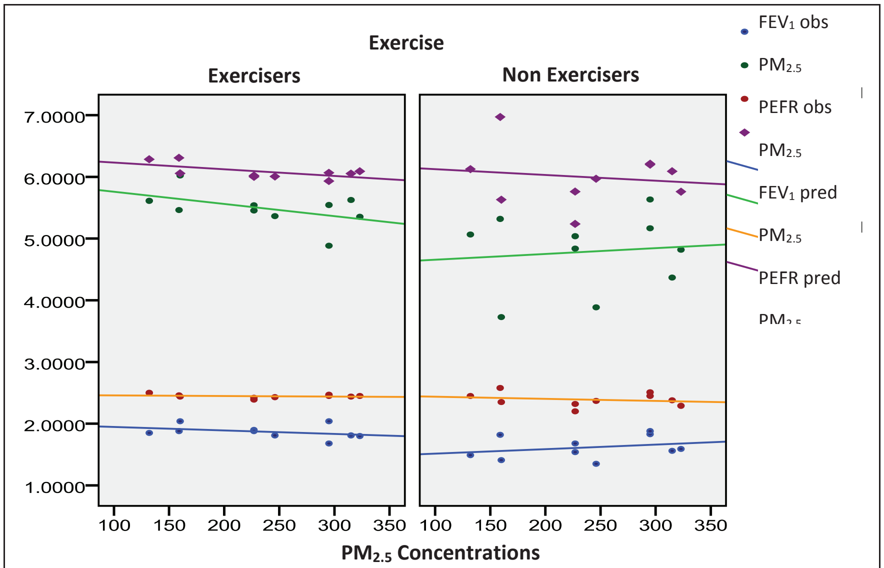

Figure 3. *Scatter plot between particulate matter ($PM_{2.5}$) and lung function parameters (FEV_1 and PEFR.) in exercisers and non exercisers.*

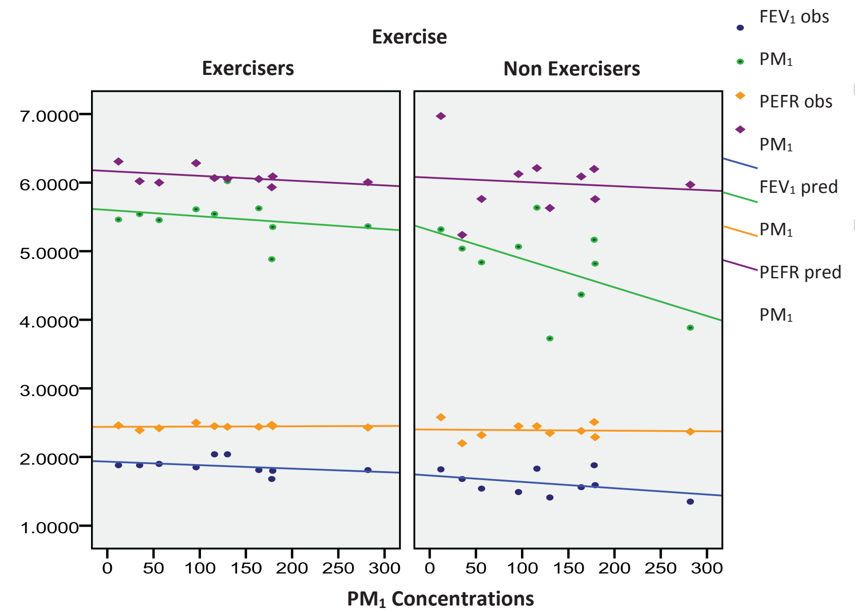

Figure 4. *Scatter plot between particulate matter (PM_1) and lung function parameters (FEV_1 and PEFR.) in exercisers and non exercisers.*

Table 1. *Physical characteristics, pulse and lung functions of study subjects*

Parameters	Exercisers (Outdoor) (n=378) Mean±SD	Non–Exercisers (n=163) Mean±SD
Sex		
Male	164 (43.39)	69 (42.33)
Female	214 (56.61)	94 (57.67)
Age	30.62±10.56	32.80±8.80
Height	162.78±10.06	162.16±8.98
Weight	57.63±11.09	60.56±12.53 [a]
BMI	21.72±3.68	22.98±4.03 [a]
Body Fat%	23.18±8.01	28.09±7.34 [b]
FEV_1 observed	1.86±0.60	1.59±0.48 [b]
FEV_1 predicted	2.43±0.58 [c]	2.37±0.61 [c]
PEFR observed	326.88±108.43	285.05±92.60 [b]
PEFR predicted	361.07±79.85 [c]	358.25±79.05 [c]
Pulse	74.08±4.01	71.99±4.12 [b]

[a] $p<0.01$, [b] $p<0.001$ for comparisons made between exercisers and non exercisers. [c] $p<0.001$, for comparisons made between the observed and predicted values of FEV_1 and PEFR within exercisers and non exercisers

Table 2. *Particulate Matter concentrations in ambient air at different locations of study subjects*

Locations	$PM_{2.5}$ (µg/m^3) [a]	PM_1 (µg/m^3) [b]
Bhaktiyarpur	282	246
Bhangal	315	164
Bisrakh	160	130
Budhera	227	56
Chandu	132	96
Dhankot	323	179
Garhi	227	35
Hazipur	295	116
Maharishi Nagar	159	12
Sadhrana	295	178

[a] Recommended limits by CPCB, India=60 ppm; [b] No recommended limits

Deposition of inhaled particles in the respiratory tract is governed by factors such as particle size, anatomical features of the airway, and breathing patterns of individuals (Sarangapani and Wexler, 2000). The particles that deposit on the respiratory tract lining do not get exhaled based on their diameter size, thereby causing respiratory health problems (Daigle et al., 2003; Chalupa et al., 2004). Sarangapani and Wexler (2000) broadly divided the lung into conducting (generations 0–14) and pulmonary regions (generations 15–23). The deeper the particles penetrate into the lung, smaller are the airway dimensions, and higher is the particle deposition efficiency due to diffusion and sedimentation increases, thus, enhancing pulmonary deposition (Sarangapani and Wexler, 2000). Exercise increases the deposition fraction and leads to a 3– to 4.5–fold increase in the number of particles deposited in airways during light exercises, and a 6– to 10–fold increase during high–intensity exercises (Daigle et al., 2003; Oravisjarvi et al., 2011). PM–exposed individuals, including the general public and professional athletes, are susceptible to pulmonary inflammation, decreased lung function, increased risk of asthma, vascular endothelial dysfunction and mild elevations in pulmonary artery pressure and diminished exercise performance (Cutrufello et al., 2012). The impairment of respiratory defenses like lesser nasal mucociliary clearance and reduction in nasal cilia beat frequency was observed among exercisers due to continuous exposure to air pollutants (Bennett et al., 1985; Muns et al., 1995; Salzano et al., 2000). Thus, hindrance of fine particles can lead to free flow of air during the breathing process and associated reduction in lung functions among outdoor exercisers. Similar trend of lung functions in general populations exposed to PM was also observed in a North Indian cross–sectional study (Kesavachandran et al., 2013).

Table 3. *Self reported respiratory health problems among study subjects*

Respiratory Health Problems	Exercisers (Outdoor) (n=378) n (%)	Non–Exercisers (n=163) n (%)
No symptoms	320 (84.66)	134 (82.21)
Breathlessness	20 (5.29)	10 (6.13)
Cold	5 (1.32)	2 (1.23)
Cough	23 (6.08)	9 (5.5)
Cough and cold	6 (1.59)	3 (1.84)
Cough with breathlessness	2 (0.53)	0 (0.0)
Productive cough	2 (0.53)	5 (3.07)

In India, particulate matter concentrations in winter are reportedly higher than those in summer and monsoon (Deshmukh et al., 2012a). Apart from biomass burning, increased energy use and dry atmospheric conditions contribute to increasing particulate matter concentrations in winter, while increased precipitation contributes to the opposite trend in the monsoon (Deshmukh et al., 2012a; Deshmukh et al., 2013b). Hence, more studies are required on the outdoor exercisers with respect to winter and summer seasons. PM_{10} concentration was about 2.6 and 1.9 times higher than pre–Diwali and post–Diwali Festival period, respectively due to the bursting of fire crackers (Nirmalkar et al., 2013). The deterioration of ambient air quality due to anthropogenic activities such as the use of firecrackers in the megacities of India has significant impacts on human health on a regional scale (Verma and Deshmukh, 2014). Thus, the Diwali period may also pose health risks to outdoor exercisers.

Some studies suggest that the beneficial effects of exercise outweigh the adverse effects of air pollution (Wong et al., 2007; Hamer and Chida, 2008; de Hartog et al., 2010; Rojas–Rueda, et al., 2011; Dong et al., 2012; Grabow et al., 2012). The exercise reduces the likelihood of air pollution–related mortality (Wong et al., 2007; Dong et al., 2012). Earlier studies indicated that cyclists traveling in bicycle lanes, in major urban centers may be exposed to more $PM_{2.5}$ and gaseous pollutants than pedestrians (Vanwijnen et al., 1995; Kaur et al., 2005; McNabola et al., 2008; Kaur and Nieuwenhuijsen 2009; de Nazelle et al., 2011). Although there are differences in pollutant exposure between cyclists and pedestrians, whether such differences result in health effects is unclear (Giles and Koehle, 2014). More research is required to assess whether exercisers actually benefit from outdoor exercise in polluted air (Giles and Koehle, 2014).

Table 4. *Predicted fall in FEV_1 and PEFR of outdoor exercisers with respect to increase in PM_1*

Change in PM_1 from Minimum Value to Maximum Percentile Values	Difference in Predicted PEFR	% Fall in Predicted PEFR	Difference in Predicted FEV_1	% Fall in Predicted FEV_1
12 (min.)–56.5 (25th percentile)	2.58	0.78	0.04	2.32
12 (min.)–87.5 (50th percentile)	4.38	1.32	0.08	3.93
12 (min.)–120.5 (75th percentile)	6.29	1.89	0.11	5.65
12 (min.)–179 (max.)	9.69	2.91	0.17	8.69

Table 5. *Predicted fall in FEV₁ and PEFR of outdoor exercisers with respect to increase in PM2.5*

Change in $PM_{2.5}$ from Minimum Value to Maximum Percentile Values	Difference in Predicted PEFR	% Fall in Predicted PEFR	Difference in Predicted FEV_1	% Fall in Predicted FEV_1
50 (min.)–100 (25th percentile)	3.25	0.96	0.05	2.56
50–159 (50th percentile)	7.08	2.09	0.11	5.58
50–194.5 (75th percentile)	9.39	2.78	0.14	7.40
50 (min.)–323 (max.)	17.75	5.24	0.27	13.98

During exercise, many physiological changes occur that can exacerbate the health effects of air pollution (Giles and Koehle, 2014). At sub–maximal exercise levels, the mode of breathing switches from predominantly nasal to oral (Niinimaa et al., 1980). This transition causes the nasal filtration system to be bypassed, potentially increasing the intake of the pollutant dose, which may exacerbate the health effects of air pollution (Giles and Koehle, 2014). Also, air pollutants like ozone are respiratory irritants that can alter breathing patterns during exercise by increasing breathing frequency and decreasing tidal volume (Adams, 2002; Adams, 2003; Alfaro et al., 2007). Breathing frequency and Minute Ventilation (VE) are influenced by the uptake of ozone and carbon monoxide; higher concentration of pollutant inhaled can lead to more serious health effects (Tikuisis et al., 1992; Ultman et al., 2004). The oral cavity being devoid of any filtration mechanism for the inhaled air, particulate matter (PM) present in the polluted ambient air freely enters the respiratory tract during outdoor exercise (Cutrufello et al., 2012). If high Air Quality Index values have been encountered, it is advisable that outdoor activities are either lessened or replaced with appropriate indoor ones (Campbell et al., 2005).

The highest PM_{10} value was recorded at Durg City in India during winter, a period characterized by extensive biomass burning, especially at night, while the lowest PM_{10} concentration was recorded during the monsoon, when there was significant precipitation (Deshmukh et al., 2012a). The concentration of Na^+, Mg^{2+}, and Ca^{2+} were higher in spring and summer at Raipur city, India (Deshmukh et al., 2013c). The seasonal variation of secondary components NH_4^+, NO_3^-, and SO_4^{2-} were similar, i.e., higher concentration in winter and lower in the falls at Durg City (Deshmukh et al., 2012a). The highest concentrations of dicarboxylates were observed during winter and spring. On an average, total water–soluble dicarboxylates accounted for 0.39% of the PM_{10} mass. Oxalate (C2), followed by malonate (C3) and succinate (C4) dominated the total mass of dicarboxylates, the sum of these three species accounting for 77.5% of the total analyzed (Deshmukh et al., 2012b). The higher concentration of PM_{10} mass was found during winter season followed by spring and summer and lower during monsoon season in Raipur, India (Deshmukh et al., 2012c). High PM_{10} mass concentrations in Raipur could be attributed to the anthropogenic activities, which may include high rate of construction activities, biomass combustion and mechanical erosion from road dusts (Deshmukh et al., 2012c).

The health effects of air pollution may persist for hours following exposure. Therefore, the role of exposure prior to exercise should be taken into consideration (Giles and Koehle, 2014). Physical exertion is a key criterion for measuring exposure, as it strongly impacts the quantity of a pollutant inhaled (Betts, 2012). Unfortunately, the quantitative relation between the level of physical exertion and amount of pollutant inhaled is still obscure and unexplored (Carlisle and Sharp, 2001). The risk and degree of particulate matter exposure during outdoor exercisers in areas of traffic congestion is difficult to predict because the concentration and movement of PM depend on wind speed, wind direction and temperature (Carlisle and Sharp, 2001). Earlier studies on chemical characterization of PM compounds at residential areas of New Delhi, India shows that the levels of Fe, Cd, Pb, Zn, Cr, Mn, Cu, Ni were within the recommended limits proposed by World Health Organization, European and US counterparts (Kumar and Tyagi, 2006; Khillare and Sarkar, 2012; Saxena and Ghosh, 2012). Indian environmental standards for ambient air are available for sulfur dioxide, nitrogen dioxide, PM_{10}, $PM_{2.5}$, ozone, lead, carbon monoxide, ammonia, benzene, benzo[*a*]pyrene (BaP), arsenic and nickel (The Gazette of India, 2009). No environmental standards for other chemicals, metals bound with PM compounds and ultrafine particles in ambient air have been proposed yet by regulatory agencies in India. In view of non availability of standards, it becomes more difficult to compare the observed concentration of these chemicals and metals. Although we did not assess the chemical characterization of PM, the study shows that the diameter of particle itself poses risk to the upper and lower airways among outdoor exercisers.

Air quality index values calculated in an earlier study showed that 35% of the days were unhealthy for sensitive people, 35% were unhealthy or very unhealthy, while 3.3% of the days were found to be hazardous in Durg City, India (Deshmukh et al., 2012a). The concentrations of SO_4^{2-} and NO_3^- were highest in all size fractions of the total mass of the water soluble ions in $PM_{2.5}$ and in PM_1 size fractions. Na^+, Mg^{2+} and Ca^{2+}, derived from the soil dust particles, were higher in spring and summer, as the dry weather in this season was favorable for the resuspension of soil particles (Deshmukh et al., 2010; Deshmukh et al., 2011). Hence, the assessment of chemical composition in PM is a concern for health risk among outdoor exercisers.

Detailed and assiduous epidemiological research is required to assess the prevalence of illnesses among those indulging in outdoor exercises (Cutrufello et al., 2012). This research need is significant considering the poor ambient air quality in India and the large population spanning across age groups and the sexes involved in regular outdoor exercises. The outdoor exercisers should consider ambient air pollution levels at their location prior to exercise, as suggested in earlier reports (Carlisle and Sharp, 2001; Campbell et al., 2005; Cutrufello et al., 2012). Smart technologies for the early detection of air pollution and traffic ahead can enlighten outdoor exercisers to change their routes accordingly (Betts, 2012). Installation of real time air quality display board by the Central Pollution Control Board, Govt. of India and other agencies at different city locations in India can be considered as a good step towards raising awareness among residents and exercisers about air pollution levels in their location.

The lack of data related to wind direction, wind speed, temperature, chemical characterization of PM and gases i.e., volatile organic compounds (VOCs), nitrogen oxides (NO_X), and sulfur oxides (SO_X) should be considered as the limitation of the study. Other limitations can be the non–usage of personal samplers to assess the particulate matter in the breathing zone and no monitoring of the nano–particle size range of PM. Dynamic lung function parameters like Maximum Voluntary Ventilation (MVV) and Forced Vital Capacity (FVC) are available in Spirometers with power supply and were not used due to power shortage in these study locations. The strength of the study was the large sample size, covering of several study locations and adjusting the results for smoking, a confounding factor for respiratory health parameters. In future, similar respiratory health studies among outdoor exercisers, with a focus on chemical characterization of PM, should be conducted in different geographical locations in India, for better understanding of the problem.

5. Conclusions

In India, millions of people exercise outdoor as a health improvement activity. However, the poor ambient air quality in Indian cities poses a crucial health risk for individuals indulging in outdoor exercise. During exercise, there is an increase in the depth of breathing process. The particulates inhaled during breathing settle onto the respiratory tract lining during exercise and do not get exhaled, thereby causing severe respiratory health problems. The impairment of respiratory defenses due to continuous exposure to air pollutants may increase the load of the air pollutants in airways during exercise. The present study showed that outdoor exercise at higher PM concentration can lead to reduced lung functions among outdoor exercisers in the National Capital Region, India. The study demonstrates that deposition of fine particles <2.5 µm in the airways results in a decline in the PEFR and FEV_1 among outdoor exercisers. More awareness programs about air pollution among the population and implementation of mitigation measures to reduce the emission sources of particulate matter in ambient air is considered as a solution for the problem.

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