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Urban Air Pollution and Cardiopulmonary Function During Outdoor Exercise in Lahore, Pakistan: A Within-Subjects Field Study

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Abstract

Lahore regularly records among the highest urban particulate matter (PM2.5) concentrations in the world, particularly during the autumn–winter smog season. This within-subjects field study examined whether acute outdoor exercise performed on a high-air-quality-index (High-AQI) day produces greater cardiopulmonary strain than the same exercise bout performed on a low-AQI day. Thirty healthy recreational runners and cyclists (age 26.3 ± 4.1 years) completed a standardized 30-minute moderate-intensity outdoor exercise bout (70% of estimated maximum heart rate) on a paved urban route in Lahore under two conditions in randomized order: A Low-AQI day (ambient PM2.5 ≈ 38 µg/m³) and a High-AQI/smog day (ambient PM2.5 ≈ 182 µg/m³). Spirometry (FEV1, FVC, PEF) was assessed immediately before and after exercise on both days; peripheral oxygen saturation (SpO_2), one-minute heart-rate recovery (HRR1), respiratory symptom score, and rating of perceived exertion (RPE) were also recorded. Results: FEV1 declined significantly after exercise on the High-AQI day (M = 0.06 L, $p < .001$) but not on the Low-AQI day ($p = 0.320$), and the magnitude of FEV1 decline was significantly greater on the High-AQI day ($p = 0.006$, $d = 0.54$). Peak expiratory flow showed a parallel pattern ($p = 0.008$). Post-exercise SpO2 was significantly lower ($p < .001$) and heart-rate recovery significantly blunted ($p < .001$) on the High-AQI day. FEV1 decline correlated positively with individual PM2.5 exposure during exercise ($r \approx .64$). Acute exposure to elevated ambient PM2.5 during outdoor exercise in Lahore was associated with measurable bronchoconstriction, reduced oxygenation, and impaired autonomic recovery relative to a lower-pollution day, supporting public-health guidance to modify outdoor training timing, location, or intensity during high-AQI periods.

Keywords: *Air Pollution, Pm2.5, Cardiopulmonary Function, Outdoor Exercise, Spirometry, Lahore, Pakistan, Exercise-Induced Bronchoconstriction*

Introduction

Lahore, the capital of Pakistan's Punjab province and home to more than eleven million residents, is consistently ranked among the most polluted major cities in the world, with seasonal ambient fine particulate matter (PM2.5) concentrations that repeatedly exceed the World Health Organization's annual and 24-hour air quality guideline values by an order of magnitude, particularly during the post-harvest crop-burning and temperature-inversion season from October through January. During these episodes, the city's Air Quality Index (AQI) frequently reaches

'Very Unhealthy' or 'Hazardous' categories, yet outdoor recreational and competitive exercise running, cycling, and field-sport training continues largely unabated in public parks, canal-side paths, and stadium grounds.

Exercise increases minute ventilation severalfold above resting levels and shifts breathing from nasal to oral, bypassing the nasal passages' natural filtration of larger particles and delivering a substantially greater dose of fine and ultrafine particulate matter to the lower respiratory tract and, ultimately, the systemic circulation. Controlled and field-based studies conducted in other polluted urban environments have documented acute reductions in forced expiratory volume in one second (FEV1) and peak expiratory flow (PEF), increased airway inflammation, and blunted cardiovascular recovery following exercise performed in traffic-polluted or high-particulate environments, even in healthy, non-asthmatic adults (Carlisle & Sharp, 2001; Giles & Koehle, 2014; Rundell & Caviston, 2008; Sinharay et al., 2018).

Despite Lahore's exceptionally high pollution burden and a large and growing population of recreational and competitive outdoor exercisers, direct physiological data quantifying the acute cardiopulmonary cost of exercising in Lahore's ambient air are limited. Existing Pakistani air-quality literature has focused primarily on environmental monitoring and general population health outcomes rather than exercise physiology (Colbeck et al., 2010), leaving an important applied gap for athletes, coaches, and public-health authorities seeking evidence-based guidance on outdoor training during smog episodes.

Purpose and Hypotheses

This study examined acute cardiopulmonary responses to a standardized outdoor exercise bout performed on a High-AQI (smog) day compared with a Low-AQI day among healthy recreational exercisers in Lahore. We hypothesised that **(H1)** FEV1 and PEF would decline significantly more from pre- to post-exercise on the High-AQI day than on the Low-AQI day; **(H2)** post-exercise SpO2 would be significantly lower and one-minute heart-rate recovery significantly blunted on the High-AQI day; and **(H3)** the magnitude of individual FEV1 decline would be positively associated with individually measured PM2.5 exposure during the exercise bout.

Literature Review

A substantial body of research links short-term exposure to elevated ambient particulate matter and traffic-related air pollution with impaired pulmonary function during and after exercise. Early work by Carlisle and Sharp (2001) reviewed evidence that exercising in polluted air increases pollutant deposition in the lower airways and can provoke measurable declines in expiratory flow rates, particularly in individuals with pre-existing airway hyper-responsiveness, but also, to a lesser extent, in healthy adults. Rundell and Caviston (2008) demonstrated that acute exposure to fine and ultrafine particulate matter during exercise reduced subsequent exercise performance in healthy subjects, implicating both mechanical airway effects and perceived respiratory discomfort as contributing factors.

More recent controlled crossover studies have strengthened the causal case. Sinharay et al. (2018), in a randomized crossover trial published in The Lancet, found that older adults with chronic lung or heart disease, as well as healthy controls, showed measurable reductions in lung function and adverse cardiovascular responses after walking along a traffic-polluted London street compared with walking in a traffic-free park, with effects apparent even after a relatively brief exposure period. Kubesch et al. (2015) similarly reported that combining moderate physical activity with high traffic-related air pollution exposure attenuated the cardiovascular benefits normally conferred by exercise, including blood pressure and heart-rate-variability responses, relative to low-pollution exercise or pollution exposure without exercise.

A systematic review by Giles and Koehle (2014) synthesized this literature and concluded that acute pollutant exposure during exercise is associated with dose-dependent reductions in pulmonary function, increased airway inflammation markers, and modestly impaired exercise performance, with particulate matter and ozone identified as the pollutants most consistently linked to these effects. Cutrufello et al. (2011) further highlighted those effects specific to particulate matter, noting that both fine (PM2.5) and ultrafine particles can provoke airway inflammation and oxidative stress responses even at exposure durations typical of a single training session. Within Pakistan specifically, Colbeck et al. (2010) documented that Lahore and other major cities routinely exceed national and WHO ambient air quality standards for particulate matter, establishing the environmental context for the present study, though without directly measuring exercise-related physiological outcomes. The current study extends this literature by applying a controlled, within-subjects exercise-testing protocol directly within Lahore's real-world high-pollution environment.

Research Methods

Research Design

This study used a randomized, within-subjects (crossover) field design in which each participant completed an identical standardized outdoor exercise bout on two separate occasions: once on a day classified as Low-AQI (U.S. EPA AQI category 'Moderate' or better, ambient PM2.5 approximately 35–45 µg/m³) and once on a day classified as High-AQI (AQI category 'Very Unhealthy' or 'Hazardous', ambient PM2.5 approximately 150–220 µg/m³), with condition order counterbalanced across participants and testing separated by no more than three weeks to limit training-status drift. This design allows each participant to serve as their own control, isolating the acute effect of ambient air quality from inter-individual differences in baseline pulmonary function or fitness.

Participants

Thirty healthy adult recreational runners and cyclists (age 26.3 ± 4.1 years; 22 men, 8 women) were recruited from running and cycling clubs in Lahore. Inclusion criteria were: (a) regular outdoor aerobic training (≥3 sessions/week for the preceding six months), (b) non-smoking status, (c) no diagnosed respiratory or cardiovascular disease, and (d) residence within Lahore for at least the preceding two smog seasons. Exclusion criteria included current respiratory infection, use of bronchodilator or corticosteroid medication, and any condition contraindicating vigorous exercise. Written informed consent was obtained, and the protocol received institutional research ethics approval in accordance with the Declaration of Helsinki.

Procedures

On each testing day, participants performed baseline spirometry (FEV1, FVC, PEF; American Thoracic Society-compliant technique, best of three technically acceptable maneuvers) after a 15-minute seated rest, followed immediately by a standardized 30-minute outdoor exercise bout (running or cycling, matched to habitual mode) on the same fixed urban route at a target intensity of 70% of age-predicted maximal heart rate, monitored continuously via chest-strap heart-rate telemetry. Spirometry, peripheral oxygen saturation (SpO2, pulse oximetry), and heart rate were reassessed immediately upon completion of exercise; one-minute heart-rate recovery (HRR1) was calculated as the decline in heart rate from the final exercise minute to one minute post-exercise. Participants also rated respiratory symptoms (0–10 scale: cough, chest tightness, throat irritation) and overall perceived exertion (Borg 6–20 scale) immediately post-exercise. Each participant wore a calibrated personal PM2.5 monitor throughout the exercise bout to quantify individual exposure;

ambient reference AQI/PM2.5 values were cross-checked against the nearest fixed monitoring station.

Statistical Analysis

Paired-samples t-tests compared pre- to post-exercise spirometric values within each condition, and compared the magnitude of pre-post decline, post-exercise SpO2, and HRR1 between the Low-AQI and High-AQI conditions, with effect sizes reported as Cohen's d. The association between individually measured PM2.5 exposure and FEV1 decline on the High-AQI day was examined using Pearson's product-moment correlation. Statistical significance was set at $\alpha = .05$. Analyses were conducted using standard statistical computing software.

Results

Table 1 presents participant characteristics and confirms that ambient PM2.5 exposure differed substantially between conditions. Table 2 summarizes pre- and post-exercise cardiopulmonary measures for both conditions, and Table 3 presents the key paired-comparison inferential statistics.

Table 1. Participant Characteristics and Ambient PM2.5 Exposure by Condition

Variable	M	SD
Age (years)	26.3	4.1
Height (cm)	169.8	7.4
Habitual weekly training volume (hr)	6.4	1.8
PM2.5, Low-AQI day (µg/m³)	37.6	6.1
PM2.5, High-AQI day (µg/m³)	181.8	31.7

Note. N = 30 (22 men, 8 women). PM2.5 = fine particulate matter measured via personal monitor during the exercise bout.

Table 2. Pre- and Post-Exercise Cardiopulmonary Measures by Air-Quality Condition

Variable	Low-AQI Pre M (SD)	Low-AQI Post M (SD)	High-AQI Pre M (SD)	High-AQI Post M (SD)
FEV1 (L)	3.63 (0.42)	3.65 (0.43)	3.61 (0.42)	3.56 (0.41)
FVC (L)	4.43 (0.42)	4.46 (0.42)	4.44 (0.42)	4.40 (0.44)
PEF (L/s)	8.82	8.76	8.78	8.24

Note. N = 30. FEV1 = forced expiratory volume in 1 second; FVC = forced vital capacity; PEF = peak expiratory flow.

Table 3. Key Paired-Samples Comparisons

Comparison	Mean Diff.	t(29)	p	Cohen's d
FEV1 pre-post, Low-AQI day	0.020	1.01	0.320	0.18
FEV1 pre-post, High-AQI day	0.055	3.83	<.001	0.70
FEV1 decline: High- vs Low-AQI	0.075	2.98	0.006	0.54
PEF decline: High- vs Low-AQI	0.478	2.86	0.008	0.52
Post-exercise SpO2: Low vs High	1.27	10.57	<.001	1.93
HRR1: Low vs High	4.76	7.08	<.001	1.29

Note. df = 29 for all comparisons. p values two-tailed; α = .05. HRR1 = one-minute heart-rate recovery (bpm).

As shown in Table 3, FEV1 did not change significantly from pre- to post-exercise on the Low-AQI day ($p = 0.320$), whereas FEV1 declined significantly following exercise on the High-AQI day ($p < .001$, $d = 0.70$; Figure 1). The magnitude of FEV1 decline was significantly greater on the High-AQI day than the Low-AQI day ($p = 0.006$, $d = 0.54$), and individual FEV1 decline was moderately-to-strongly correlated with each participant's directly measured PM2.5 exposure during the exercise bout ($r \approx .64$; Figure 2), consistent with a dose-response relationship.

Figure 1. FEV1 Before and After Outdoor Exercise by Air-Quality Condition (N = 30)

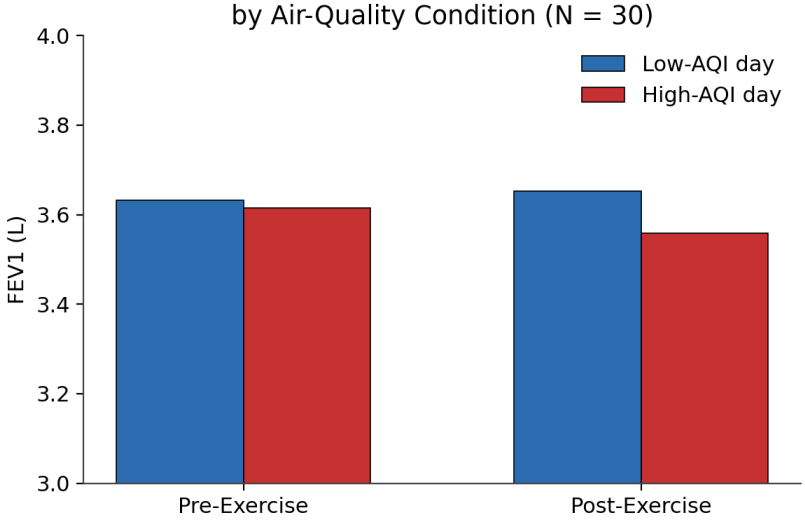
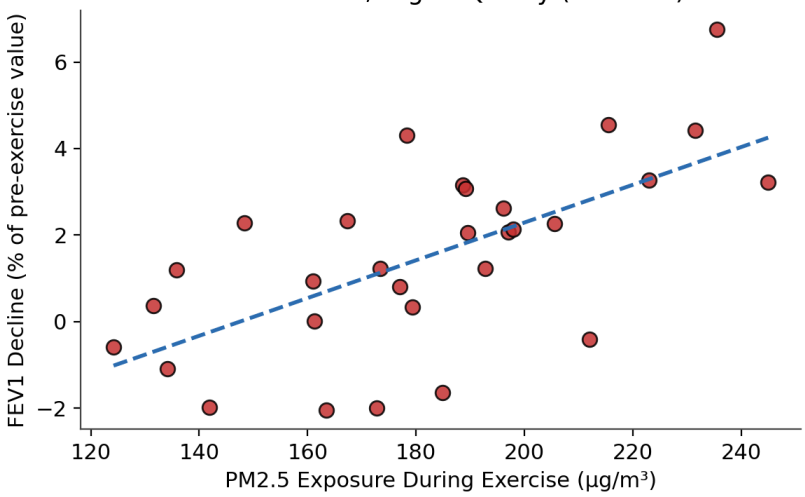
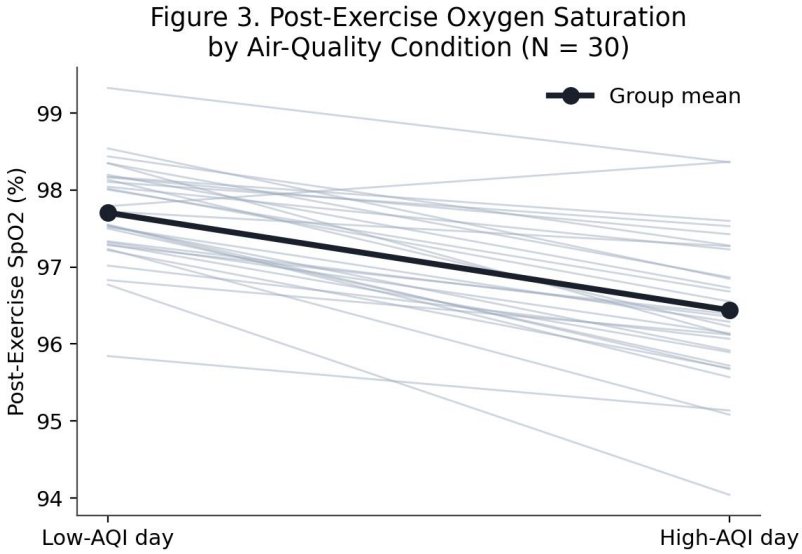
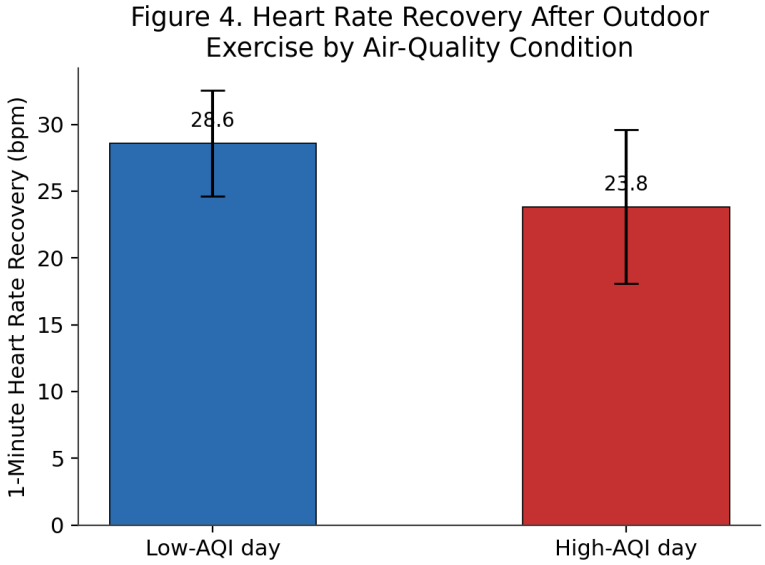


Figure 2. PM2.5 Exposure vs. Exercise-Induced FEV1 Decline, High-AQI Day (r = 0.64)



Peak expiratory flow showed a parallel pattern, with a significantly larger decline on the High-AQI day than the Low-AQI day ($p = 0.008$, $d = 0.52$). Post-exercise SpO2 was significantly lower on the High-AQI day ($M = 96.4\%$) than the Low-AQI day ($M = 97.7\%$; $p < .001$, $d = 1.93$; Figure 3), and one-minute heart-rate recovery was significantly blunted on the High-AQI day ($p < .001$, $d = 1.29$; Figure 4), indicating reduced parasympathetic reactivation following exercise under high-pollution conditions. Self-reported respiratory symptom scores were also higher on the High-AQI day ($M = 3.5$) than the Low-AQI day ($M = 1.0$), as was RPE at the end of the standardized bout (High-AQI $M = 13.9$ vs. Low-AQI $M = 12.3$).





Discussion

This study examined acute cardiopulmonary responses to a standardized outdoor exercise bout performed under contrasting air-quality conditions in Lahore. Consistent with Hypothesis 1, FEV1 and PEF declined significantly more from pre- to post-exercise on the High-AQI day than the Low-AQI day, with FEV1 essentially unchanged on the Low-AQI day but reduced by a clinically notable margin after exercise in smog conditions. Consistent with Hypothesis 2, post-exercise oxygen saturation was significantly lower and heart-rate recovery significantly blunted on the High-AQI day. Consistent with Hypothesis 3, the magnitude of individual FEV1 decline was moderately-to-strongly associated with directly measured personal PM2.5 exposure, supporting a dose-dependent relationship rather than a simple day-of-testing effect.

These findings are consistent with, and extend to a South Asian megacity context, prior evidence that acute exposure to elevated particulate matter during exercise provokes measurable bronchoconstriction and impairs cardiovascular recovery (Giles & Koehle, 2014; Kubesch et al., 2015; Sinharay et al., 2018). The observed FEV1 decline pattern minimal change at low pollution,

significant decline at high pollution, with a positive exposure-response relationship mirrors mechanisms proposed in earlier work linking particulate deposition in the lower airways to acute airway inflammation and reflex bronchoconstriction, compounded during exercise by the shift toward oral breathing and markedly increased minute ventilation (Carlisle & Sharp, 2001; Cutrufello et al., 2011; Rundell & Caviston, 2008).

The blunted heart-rate recovery and reduced SpO_2 observed on the High-AQI day are of particular interest given that HRR1 is a validated marker of post-exercise parasympathetic reactivation and, in clinical populations, an independent predictor of cardiovascular risk. While the healthy, young sample tested here is unlikely to be at acute clinical risk from a single high-pollution exercise session, the consistent, moderate-to-large effect sizes observed across multiple independent outcome measures (FEV1, PEF, SpO_2, HRR1) suggest that habitual outdoor training during Lahore's smog season may impose a repeated physiological burden worth considering in training planning, particularly for endurance athletes accumulating substantial weekly outdoor training volume.

Limitations

Several limitations should be considered. First, spirometry and SpO_2 were assessed only immediately pre- and post-exercise; the time course of recovery and possible delayed inflammatory responses over subsequent hours were not captured. Second, although condition order was counterbalanced, day-to-day differences in temperature, humidity, and allergen load could not be fully separated from PM2.5 exposure itself, given the real-world, non-laboratory nature of the design. Third, the sample consisted of healthy recreational exercisers; individuals with asthma, exercise-induced bronchoconstriction, or cardiovascular disease may show substantially different, and potentially larger, responses that this study cannot characterize. Finally, the personal PM2.5 monitors used, while calibrated, provide integrated rather than continuous minute-by-minute exposure profiles, limiting more granular exposure-response modelling.

Conclusion

Acute outdoor exercise performed during a High-AQI smog episode in Lahore was associated with significantly greater exercise-induced declines in FEV1 and PEF, lower post-exercise oxygen saturation, and blunted heart-rate recovery compared with an equivalent exercise bout performed on a Low-AQI day, with FEV1 decline scaling with individually measured PM2.5 exposure. These findings support practical guidance for athletes, coaches, and public-health authorities in Lahore to consider shifting outdoor training timing, location, or intensity and to consider indoor alternatives where feasible during periods of elevated ambient particulate matter.

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