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Effects of short-term air pollution on aerobic performance and forced vital capacity (FVC): An experimental analysis

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ABSTRACT

Background Problems: Exercising in environments with varying levels of air pollution poses potential health risks, but the short-term physiological impacts remain underexplored. This study focusses on evaluating how air pollution affects aerobic capacity and lung function during physical activity. **Research Objectives:** The objective of this research is to compare the short-term effects of low and high air pollution exposure on aerobic performance (VO2max) and lung function (forced vital capacity or FVC) among physically active individuals. **Methods:** A quasi-experimental posttest-only crossover group design was employed. Twenty students from the Faculty of Sports and Health Education, Universitas Pendidikan Indonesia (UPI), Bandung, participated in the study. VO2max and FVC were measured in two different environments, characterised by low and high air pollution levels, and the results were compared. **Findings and Results:** The findings showed a slight, statistically insignificant reduction in aerobic performance (VO2max) under high air pollution (51.83±1.45) compared to low air pollution (52.41±1.47) conditions ($p = 0.310$). However, a significant decrease in FVC was observed under high pollution conditions compared to low pollution ($p = 0.014$). **Conclusion:** The study concludes that short-term exposure to high levels of air pollution does not significantly impact aerobic performance but does lead to a considerable reduction in forced vital capacity. Future studies should also control for environmental factors like temperature and humidity, as well as assess the role of individual susceptibility, such as pre-existing respiratory or cardiovascular conditions. Furthermore, exploring additional physiological variables, such as inflammatory markers or oxidative stress indicators, could provide a more comprehensive understanding of how air pollution impacts physical performance and health.

Keywords: Air pollution; aerobic performance; forced vital capacity; lung function

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INTRODUCTION

Walking, cycling, running, and other exercise activities are widely considered to offer numerous benefits for both physical and mental health (Huang et al., 2016). However, physical activity can also increase the rate of respiration. Previous studies have reported that oxygen consumption during activities like walking, running, and cycling ranges from 1000 to 5000 ml per minute, contingent upon the intensity of the exercise (Andersen et al., 2015; Ramos et al., 2014) thus, when performed in areas exposed to air pollution, can negatively impact human health. One type of air pollution that has recently gained much attention is fine particulate matter with a diameter of less than 2.5 mm ($PM_{2.5}$) (Hu et al., 2017). $PM_{2.5}$ consists of a mixture of solid and liquid particles suspended in the air, primarily originating from the combustion of fossil fuels during heating, power generation, and motor vehicle operation (Xing et al., 2016). Previous literature suggests that ambient exposure to particulate matter (PM) logically tends to increase health risks during aerobic endurance (Fisher et al., 2016).

Aerobic physical activity is a type of exercise that involves repetitive and long-term muscle work, with sufficient intensity to stimulate increased oxygen demand. Aerobic exercise can increase a person’s cardiovascular and respiratory capacity, as measured by VO2max, which is the maximum volume of oxygen that can be absorbed by the body during intensive physical activity. VO2max is often used as the main indicator in measuring a person’s aerobic endurance (Apriantono et al., 2020). The higher the VO2max, the greater the body's ability to use oxygen efficiently, thereby improving physical performance. However, the environment in which physical activity is carried out, especially air quality, can affect the results of the VO2max test. Polluted environments, especially with $PM_{2.5}$ particles, can affect lung function and reduce the body’s oxygen transport capacity (Giles & Koehle, 2014).

Aerobic endurance refers to the highest oxygen uptake achieved during dynamic exercise over a certain duration performed under normal conditions. The more efficient the aerobic process, the greater the aerobic capacity (Lorenz et al., 2013). Therefore, aerobic endurance is typically assessed using a VO2max test. High levels of air pollution can lead to a decrease in maximal oxygen consumption (VO2max), possibly due to reduced oxygen transport from the alveoli in the lungs (Bahri et al., 2019b; Xing et al., 2016). Additionally, there is substantial evidence documenting the adverse effects of both short-term and long-term exposure to $PM_{2.5}$, including increased blood pressure, myocardial infarction, stroke, and respiratory diseases such as asthma and bronchitis (Lorenz et al., 2013).

$PM_{2.5}$ particles, which have a diameter of less than 2.5 micrometres, are able to penetrate deep into the respiratory tract, even reaching the lung alveoli, potentially causing short-term and long-term damage to the respiratory system (Xing et al., 2016). In the context of physical exercise, when a person exercises in an environment polluted by $PM_{2.5}$, the respiratory rate and volume of air entering the lungs will increase, thereby increasing the risk of exposure to these particles. Possible short-term effects include respiratory tract irritation, decreased lung function, and increased systemic inflammation, which can contribute to decreased physical performance (Sagheer et al., 2024). Conversely, physical exercise performed in an environment with clean air can actually increase respiratory efficiency and strengthen lung capacity in the long term.

On the other side, there is still much debate about the risks and benefits of exercising in polluted environments (Giles & Koehle, 2014). Research reveals that increased concentrations of fine particulate matter (PM_1) are significantly associated, both statistically and clinically, with impaired lung function (Tainio et al., 2021). Additionally, other studies indicate that increased exposure to $PM_{2.5}$ can worsen the possibility of experiencing lung function impairment by two times or more (Sagheer et al., 2024). Several studies have reported the short-term effects of air pollution on increased mortality risk, which can indicate the process of atherosclerosis, marked by changes in the production of blood cells (Künzli et al., 2010). This issue presents an intriguing challenge in balancing the benefits of exercise with the adverse effects of air pollution on health.

Furthermore, only a few studies related to the effects of PM on respiratory parameters during aerobic exercise are carried out, with most studies focusing on ozone and few specifically on PM (Sagheer et al., 2024). A specific review on PM associated with aerobic endurance was recently published by Cutrufello and colleagues (Allen, 2013). His review cites studies reporting decreased Forced Vital Capacity (FVC) and Forced Expiratory Volume in the first second (FEV_1) among healthy individuals (Tainio et al., 2021), and in asthma subjects conducted in urban areas (Guarnieri & Balmes, 2015), and an increase in blood neutrophil concentrations following intermittent exercise during exposure. The health benefits and risks of exercising in polluted environments need to be compared to assess the extent of the impact of polluted environments on health. Heretofore, researchers have not found any studies comparing two locations with different pollutant levels on VO2max and forced vital capacity.

The urgency of this study stems from the growing concern over air pollution's impact on public health, particularly in urban areas where pollution levels are consistently high. Although extensive research has been conducted on the effects of air pollutants like ozone on respiratory health during exercise (Giorgini et al., 2016), the specific impact of particulate matter (PM) on aerobic performance and respiratory parameters remains largely unexplored. Given the increasing prevalence of cardiovascular and respiratory issues, compounded by rising pollution levels, it is crucial to understand how exercising in polluted environments affects lung capacity and aerobic endurance. Therefore, this research aims to examine the short-term effects of exercising in environments polluted by $PM_{2.5}$ on VO2max and forced vital capacity, with varied concentrations of PM. The research results can provide guidelines for determining the appropriate times to engage in physical activity, especially under conditions of low and high pollution levels.

METHOD

The research method employed a quasi-experimental posttest-only crossover design. Each group received the same treatment but in different locations. Two areas (low and high air pollution) were selected based on real-time measurements conducted using AirVisual Pro before and during the study (UPI Bandung stadium with low pollution and SARAGA field with high pollution). These locations were chosen because they had the same temperature and humidity parameters but different pollution levels. In this research, all subjects were quarantined for 21 days: the first 7 days in the low pollution area, followed by a 7-day recovery period, and then 7 days in the high pollution area.

A total of 20 healthy amateur futsal athletes participated in this research (mean ± standard deviation): age 19.80 ± 1.01 years, height 165.70 ± 5.30 cm, weight 54.88 ± 4.48 kg, FAT 12.86 ± 2.48%, and BMI 19.82 ± 1.00 kg/m2. All subjects were asked to fill out and sign informed consent forms after receiving a thorough explanation of the study protocol. The eligibility criteria for this study included subjects who regularly engaged in aerobic exercise 2-3 times per week, aged 18-21 years, were male, non-smokers, and non-alcohol drinkers, had no history of chronic or acute diseases, and were not taking any medications or vitamin supplements during the past week. Before the initial test, subjects were instructed to follow a meal schedule (breakfast at 08:00 ± 01:00, lunch at 12:00 ± 01:00, and dinner at 20:00 ± 01:00). All energy intakes for participants were set at 2500 kcal per day. Additionally, subjects with obesity, cardiovascular, pulmonary, or renal disorders were excluded from this study. During the experimental period, participants were asked to maintain their habitual physical activity and avoid strenuous physical exercise 24 hours before the test sessions began.

Measurements and Research Procedures

Anthropometry

A questionnaire was distributed to subjects during the test to collect the age data. Height was measured using a manual stature metre brand GEA, conducted directly by the researcher. Weight, FAT, and BMI measurements were obtained using a digital scale brand OMRON Karada Scan HBF-375 (Santos et al., 2014).

Air Pollution Parameters

Researchers used AirVisual Pro to measure pollutant levels at the two research locations. The device was placed at a height of 2-4 meters above the ground. Then, its sensor devices would record real-time data on temperature, humidity, CO_2, PM_{10}, and $PM_{2.5}$, which could be viewed through the AirVisual app on a smartphone (Bahri et al., 2019a).

Table 1. Characteristics of the Low- and High-Polluted Areas

Parameters	Low Polluted Area	High Polluted Area	Standard
$PM_{2.5}$ (µg/m3)	65.97	154.71*	<65
PM_{10} (µg/m3)	104.6	219.8*	<150
CO_2 (ppm)	466.87	499.2*	300-500
Temperature (°C)	23.65	23.98	22.8 - 25.8
Humidity (%)	67.69	66.65	45 – 65

Forced Vital Capacity (FVC) and Aerobic Performance

Forced vital capacity (FVC) was measured using a Spirometer SP10. FVC was recorded after the subjects inhaled as much air as possible and then exhaled as much air as possible (from the lungs). Meanwhile, the researchers employed the Cooper 2.4 KM test on the aerobic performance test; notably, the fastest completion times were converted to a VO2max table (Bahri et al., 2021).

Research Procedure

A week before the initial tests began, all participants were required to familiarize themselves with the testing equipment to ensure smooth execution during the study. On the first day of testing, participants underwent anthropometric measurements, followed by the treatment phase. The treatment involved light exercise (jogging) at moderate intensity (64-76% HRmax) in the morning (06:00 ± 01:00), afternoon (16:00 ± 01:00), and evening (19:00 ± 01:00) for 15 minutes over 7 days. On the 7^{th} day, all participants performed a posttest in the morning (06:00 ± 01:00) consisting of Cooper's 12-minute run test to determine their final VO2max. This was followed by FVC measurement. The FVC and VO2max results were recorded for comparison between high and low air pollution conditions.

Table 2. The Training Schedule and Intensity over the 7-day Period:

Training Schedule and Intensity Diagram
Week 0: Familiarization with Testing Equipment (1 week prior to testing)
Day 1: Anthropometric Measurements and Start of Treatment Phase
Days 1-6 (Treatment Phase): Morning: | 06:00 ± 01:00 | Light Exercise (Jogging) | Moderate Intensity (64-76% HRmax) | 15 minutes Afternoon: | 16:00 ± 01:00 | Light Exercise (Jogging) | Moderate Intensity (64-76% HRmax) | 15 minutes Evening: | 19:00 ± 01:00 | Light Exercise (Jogging) | Moderate Intensity (64-76% HRmax) | 15 minutes
Day 7 (Posttest): Morning: | 06:00 ± 01:00 | Posttest: - Cooper's 12-Minute Run Test (VO2max) - FVC Measurement

*Note: VO2max and FVC results will be compared between high and low air pollution conditions after posttest.

Data Analysis

The research data consisted of the mean values and standard deviations. The anthropometric data (age, weight, height, and BMI) was tested using a one-way ANOVA to compare the two groups. To measure air pollution conditions at the two different locations, as well as aerobic performance and FVC, a T-test analysis was conducted. All statistical analyses were performed using SPSS version 22, with a significance level set at $p < 0.01$ or $p < 0.05$.

RESULTS AND DISCUSSION

Anthropometric data can be seen in Table 3. The research results revealed that there were insignificant differences in height, weight, FAT, and BMI parameters between the two groups after undergoing treatment for 7 days in each location.

Table 3. Anthropometry Data

Anthropometry	Total Sampling (N=40)	Group		P-value
		Low Air Pollution (n=20)	High Air Pollution (n=20)	
Age	19.80 ± 1.01	19.88 ± 1.25	19.71 ± 0.76	0.772
Height (cm)	165.70 ± 5.30	166.81 ± 6.31	164.43 ± 3.95	0.405
Weight (kg)	54.88 ± 4.48	56.30 ± 3.79	53.26 ± 4.94	0.200
FAT (%)	12.86 ± 2.48	12.95 ± 2.76	12.76 ± 2.35	0.887
BMI (kg/m^2)	19.82 ± 1.00	20.06 ± 0.95	19.54 ± 1.54	0.334

BMI= Body Mass Index

A comparison of the two groups after treatment in different locations showed a delta decrease of -1.13% in aerobic performance (VO2max) under high pollution conditions compared to low pollution conditions (p = 0.310), which was not statistically significant. However, the FVC score in the high pollution group emphasised a significant decrease compared to the low pollution group, with a delta decrease of -9.98%.

Table 4. Aerobic Performance and Forced Vital Capacity

Anthropometry	Group		Delta (Δ %)	P-value
	Low Air Pollution (n=20)	High Air Pollution (n=20)		
VO_{2max} (ml/kg/hour)	52.41 ± 1.47	51.83 ± 1.45	-1.13	0.310
FVC (L)	3.56 ± 0.18	3.21 ± 0.26	-9.98	0.014*

FVC= Force Vital Capacity

The results of this study indicate that short-term exposure to high levels of air pollution does not significantly affect aerobic performance (VO2max), but it does cause a significant reduction in forced vital capacity (FVC). This reduction in FVC suggests that exposure to air pollutants can directly affect lung function, particularly in the ability to forcibly expel air after maximal inspiration. This reduction may be related to irritation of the respiratory tract due to exposure to pollutant particles, causing bronchial constriction or inflammation of the airways. Although VO2max did not show a significant decline, this result may be due to the short duration of exposure, which is insufficient to substantially impact aerobic performance, as aerobic adaptation typically requires more time to show significant effects.

Previous research also explains that this may be caused by carbon monoxide (CO), which has an extreme effect on oxygen transport (Giles & Koehle, 2014), as the binding affinity of haemoglobin (Hb) to CO is about 240 times higher than to oxygen. Consequently, carboxyhaemoglobin (COHb) will not release carbon monoxide, making haemoglobin unavailable to transport oxygen from the lungs to other organs in the body (Brook et al., 2015). This results in reduced aerobic physical activity, which can be associated with increased COHb levels, leading individuals to enter anaerobic systems earlier, which in turn decreases the anaerobic threshold and reduces maximum oxygen consumption.

The findings are consistent with previous research indicating that air pollution, particularly that containing fine particulate matter ($PM_{2.5}$), can lead to a decline in lung function in the short term, but does not always have a direct impact on aerobic capacity. A study by Giles and Koehle (2014) also reported that high air pollution exposure significantly reduced FVC in exposed athletes, while aerobic performance remained stable during short exposure periods. This may be because aerobic capacity is more influenced by cardiovascular and muscular factors, while lung function is more susceptible to irritation caused by pollutant exposure. On the other hand, long-term studies, such as those conducted by (Künzli et al. 2010), indicate that chronic exposure to air pollution can significantly affect VO2max, suggesting that the cumulative effects of air pollution warrant further investigation in the context of physical activity. This highlights the need for ongoing research into both short-term and long-term impacts of air pollution on athletic performance and overall health, particularly for individuals engaging in outdoor activities in polluted environments.

The decrease in lung function observed under high air pollution conditions after undergoing treatment showed statistically significant results (FVC; p=0.014). This research aligns with the research conducted by (Cutrufello et al., 2012). Which emphasized that before and after 30 minutes of exercise, separated by a 4-5-day interval (in low and high air pollution conditions), lung function at rest showed no change after exercise in low PM_1 conditions. However, after exercise in high PM_1 conditions, both FEV_1 and $FEF_{25–75}$ decreased significantly (p = .0005, p = .002). A decrease of 11 and 52 ml was calculated for every 20,000 cm^{-3} increase in particles for FEV_1 and $FEF_{25–75}$, respectively.

Hence, exposure to high pollution levels during exercise can lead to a decrease in FVC, which is associated with impaired lung function. The mechanism behind the decline in lung function is due to particles larger than 5 microns being stopped in the nose and throat. Although some particles can enter the lungs, they do not go further than the bronchi and are often expelled quickly by ciliary movement. However, particles sized 0.5-5 microns can enter the lungs, with some even reaching the alveoli. The removal of fine particles from the alveoli is slow and incomplete, allowing these particles to settle in the alveoli.

This leads to an interaction between particle metabolites and oxygen in the alveoli, resulting in the production of ROS (Reactive Oxygen Species). ROS oxidizes guanine into 8-oxo guanine, causing oxidative stress in the body (Møller et al., 2010). Oxidative stress is a condition where the amount of free radicals in the body exceeds its capacity to neutralize them, leading to inflammatory reactions in the lungs, which in turn limits lung expansion (Ghelfi et al., 2010). Consequently, a decline in lung function occurs in the human body (Wagner & Clark, 2018). Physical activity can lead to an increased inhalation of air pollutants due to the rise in ventilation during exercise, but this additional amount may only constitute a small fraction of the total inhaled air pollution dose (Rojas-Rueda et al., 2011). Another hypothesis is that the adverse effects caused by short-term exposure during exercise are “temporary and reversible and do not diminish the long-term benefits of regular physical activity” (Andersen, 2015).

CONCLUSION

Air pollution and physical activity are essential factors influencing health. This study contributes evidence that short-term exposure to air pollution can impede improvements in VO2max and decrease blood cell production. However, the absence of a control group limits the generalisability of these findings, as it is difficult to definitively conclude that the observed changes are solely attributable to the interventions rather than being influenced by participants’ habits and lifestyle. Additionally, while regular exercise in both high and low pollution environments did not significantly reduce forced vital capacity (FVC) or forced expiratory volume in the first second (FEV1) among healthy individuals, the protective effects of physical activity on lung function must be interpreted with caution. The lack of a control group weakens the robustness of these results and suggests that further studies, particularly longitudinal ones, are necessary to assess the long-term clinical significance of these findings. It is critical to raise awareness among individuals and sports practitioners about the potential hazards of air pollution, emphasising that regular physical activity could help mitigate its effects. Nevertheless, these conclusions should be approached with care, given the methodological constraints of the study.

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CONFLICT OF INTEREST

There are no conflicts of interest in this research.

REFERENCES

Allen, D. (2013). Small Things Make a Difference. *Nursing Children and Young People*, *25*(10), 8-9. https://doi.org/10.7748/ncyp2013.12.25.10.8.s9

Andersen, Z. J., de Nazelle, A., Mendez, M. A., Garcia-Aymerich, J., Hertel, O., Tjønneland, A., Overvad, K., Raaschou-Nielsen, O., & Nieuwenhuijsen, M. J. (2015). A Study of the Combined Effects of Physical Activity and Air Pollution on Mortality in Elderly Urban Residents: The Danish Diet, Cancer, and Health Cohort. *Environmental Health Perspectives*, *123*(6), 557-563. https://doi.org/10.1289/ehp.1408698

Apriantono, T., Herman, I., Juniarsyah, A. D., Hasan, M. F., Ihsani, S. I., Hidayat, I. I., Safei, I., Winata, B., & Hindawan, I. (2020). The Effect of Temperature and Humidity on VO2max of PPLP Athletes in Java, Indonesia. *Sportif*, *6*(1), 59-68. https://doi.org/10.29407/js_unpgri.v6i1.13872

Bahri, S., Pambudi, Y. T., Safei, I., Resmana, D., & Hindawan, I. (2019a). The Effect of Performing Exercise in Air Polluted Environments on Blood Pressure Response. *JPJO: Jurnal Pendidikan Jasmani dan Olahraga*, *4*(1), 103-110. https://doi.org/10.17509/jpjo.v7i1.45037

Bahri, S., Resmana, D., Tomo, H. S., Safei, I., & Hasan, M. F. (2019b). Aerobic Capacity Response and Hematological Profile during Performing Physical Activity at Two Public Sport Venues with Different Air Pollution Concentrations. *JPJO: Jurnal Pendidikan Jasmani dan Olahraga*, *4*(1), 103-110. https://doi.org/10.17509/jpjo.v6i1.27621

Bahri, S., Resmana, D., Tomo, H. S., & Apriantono, T. (2021). The Effect of Exercising Under Particulate Matter 2.5 Conditions on Forced Vital Capacity and Blood Lead Levels. *Physiotherapy Quarterly*, *29*(3), 24-27. https://doi.org/10.5114/pq.2020.100288

Brook, R. D., Rajagopalan, S., Iii, C. A. P., Brook, J. R., Bhatnagar, A., Diez-roux, A. V, Holguin, F., Hong, Y., Luepker, R. V, Mittleman, M. A., Peters, A., Siscovick, D., Smith, S. C., Whitsel, L., & Kaufman, J. D. (2015). Particulate Matter Air Pollution and Cardiovascular Disease an Update to the Scientific Statement from the American. *Circulation Journal Of The American Heart Association*, 2332-2378. https://doi.org/10.1161/CIR.0b013e3181dbece1

Cutrufello, P. T., Smoliga, J. M., & Rundell, K. W. (2012). Small Things make a Big Difference: Particulate Matter and Exercise. *Sports Medicine*, *42*(12), 1041-1058. https://doi.org/ 10.1007/BF03262311

Fisher, J. E., Loft, S., Ulrik, C. S., Raaschou-Nielsen, O., Hertel, O., Tjønneland, A., Overvad, K., Nieuwenhuijsen, M. J., & Andersen, Z. J. (2016). Physical Activity, Air Pollution, and the Risk of Asthma and Chronic Obstructive Pulmonary Disease. *Am J Respir Crit Care Med*, *194*(7), 855-865. https://doi.org/10.1164/rccm.201510-2036OC

Ghelfi, E., Wellenius, G. A., Lawrence, J., Millet, E., & Gonzalez-flecha, B. (2010). Cardiac Oxidative Stress and Dysfunction by Fine Concentrated Ambient Particles (Caps) are Mediated by Angiotensin-II. *Inhal Toxicol*, *22*(11), 963-972. https://doi.org/10.3109/08958378.2010.503322

Giles, L. V., & Koehle, M. S. (2014). The Health Effects of Exercising in Air Pollution. *Sports Medicine*, *44*(2), 223-249. https://doi.org/10.1007/s40279-013-0108-z

Giorgini, P. M. D., Rubenfire, M. M. D., Bard, L. M. S., Jackson, E. A. M. D.,;Ferri, C. M. D., & Brook, R. D. M. D. (2016). Air Pollution and Exercise: A Review of the Cardiovascular Implications for Health Care Professionals. *Journal of Cardiopulmonary Rehabilitation and Prevention*, *36*(2), 84-95. https://doi.org/10.1097/HCR.0000000000000139

Guarnieri, M., & Balmes, J. R. (2015). Outdoor Air Pollution and Asthma. *The Lancet*, *383*(9928), 1581-1592. https://doi.org/10.1016/S0140-6736(14)60617-6

Hu, J., Li, N., Lv, Y., Liu, J., Xie, J., & Zhang, H. (2017). Investigation on indoor air pollution and childhood allergies in households in six Chinese cities by subjective survey and field measurements. *International Journal of Environmental Research and Public Health*, *14*(9), 1-21. https://doi.org/10.3390/ijerph14090979

Huang, J., Zhou, C., Zhuo, Y., Xu, L., & Jiang, Y. (2016). Outdoor Thermal Environments and Activities in Open Space: An Experiment Study in Humid Subtropical Climates. *Building and Environment*, *103*, 238-249. https://doi.org/10.1016/j.buildenv.2016.03.029

Künzli, N., Jerrett, M., Garcia-Esteban, R., Basagaña, X., Beckermann, B., Gilliland, F., Medina, M., Peters, J., Hodis, H. N., & Mack, W. J. (2010). Ambient Air Pollution and the Progression of Atherosclerosis in Adults. *PLoS ONE*, *5*(2), e9096. https://doi.org/10.1371/journal.pone.0009096

Lorenz, D. S., Reiman, M. P., Lehecka, B. J., & Naylor, A. (2013). What Performance Characteristics Determine Elite Versus Nonelite Athletes in the Same Sport?. *Sports Health*, *5*(6), 542-547. https://doi.org/10.1177/1941738113479763

Møller, P., Jacobsen, N. R., Folkmann, J. K., Pernille, H., Mikkelsen, L., Hemmingsen, J. G., & Vesterdal, L. K. (2010). Role of Oxidative Damage In Toxicity of Particulates. *Free Radical Research*, *44*(1), 1-46. https://doi.org/10.3109/10715760903300691

Ramos, C. A., Wolterbeek, H. T., & Almeida, S. M. (2014). Exposure to Indoor Air Pollutants during Physical Activity in Fitness Centers. *Building and Environment*, *82*, 349-360. https://doi.org/10.1016/j.buildenv.2014.08.026

Rojas-Rueda, D., de Nazelle, A., Tainio, M., & Nieuwenhuijsen, M. J. (2011). The Health Risks and Benefits of Cycling in Urban Environments Compared with Car Use: Health Impact Assessment Study. *BMJ*, *343*(aug042), d4521. https://doi.org/10.1136/bmj.d4521

Sagheer, U., Al-Kindi, S., Abohashem, S., Phillips, C. T., Rana, J. S., Bhatnagar, A., Gulati, M., Rajagopalan, S., & Kalra, D. K. (2024). Environmental Pollution and Cardiovascular Disease. *JACC: Advances*, *3*(2), 1-10. https://doi.org/10.1016/j.jacadv.2023.100805

Santos, D. A., Dawson, J. A., Matias, C. N., Rocha, P. M., Minderico, C. S., Allison, D. B., Sardinha, L. B., & Silva, A. M. (2014). Reference Values for Body Composition and Anthropometric Measurements in Athletes. *PLoS ONE*, *9*(5), 1-11. https://doi.org/10.1371/journal.pone.0097846

Tainio, M., Jovanovic Andersen, Z., Nieuwenhuijsen, M. J., Hu, L., de Nazelle, A., An, R., Garcia, L. M. T., Goenka, S., Zapata-Diomedi, B., Bull, F., & Sá, T. H. de. (2021). Air Pollution, Physical Activity and Health: A Mapping Review of the Evidence. *Environment International*, *147*, 1-15. https://doi.org/10.1016/j.envint.2020.105954

Wagner, D. R., & Clark, N. W. (2018). Effects of Ambient Particulate Matter on Aerobic Exercise Performance. *Journal of Exercise Science and Fitness*, *16*(1), 12-15. https://doi.org/10.1016/j.jesf.2018.01.002

Xing, Y. F., Xu, Y. H., Shi, M. H., & Lian, Y. X. (2016). The Impact of PM2.5 on the Human Respiratory System. *Journal of Thoracic Disease*, *8*(1), E69-E74. https://doi.org/10.3978/j.issn.2072-1439.2016.01.19