

EVALUATION OF THE IMPACT OF AIR QUALITY AND ITS EFFECTS ON THE ATHLETES' HEALTH

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ABSTRACT

Background: Air pollution is an important determinant of public health, particularly in outdoor sports contexts involving prolonged exposure. **Objectives:** To evaluate air pollutant levels and meteorological variables in an urban and a rural area and analyze their impact on the respiratory health of football players. **Methodology:** An observational, descriptive, and analytical cross-sectional study was conducted in 2025 with 63 participants. Environmental parameters (CO, CO₂, VOC, PM_{2.5}, PM₁₀, and ultrafine particles), temperature, and relative humidity were measured, and a health questionnaire was applied. **Results:** Significant differences were observed between locations, with higher pollutant concentrations in the rural area, although within legal limits. Exposure varied according to training periods, and interactions between location and exposure time were identified. Respiratory symptoms, including asthma, dry cough, headaches, and rhinitis, were more frequent among players training in urban environments. Seasonal and meteorological factors influenced symptom prevalence, with greater aggravation during winter and spring. **Conclusions:** The findings support the integration of environmental monitoring and preventive measures into sports planning to protect athletes' health and performance.

Keywords: Respiratory Health, Football Players, Particulate Matter, Urban Vs Rural, Environmental Monitoring.

1. INTRODUCTION

Air is essential for life. Humans can go a few days without eating, a few hours without drinking water, but only a few minutes without breathing. Substances released into the atmosphere, whether by natural processes or human activities, can impact air quality in countless ways, depending on their chemical composition, concentration, meteorological conditions and topographical characteristics of the location, thus contributing to air pollution (APA, 2021). According to the World Health Organization (WHO), pollution is defined as “contamination of the internal or external environment by any chemical, physical or biological agent that modifies the natural characteristics of the atmosphere” (WHO, 2025).

The 21st century has brought significant advances, such as increased quality of life and longevity, but it has also intensified environmental challenges associated with urban growth and globalization. In urban areas, continuous population growth, combined with economic development and the expansion of urbanization, has aggravated environmental problems, especially air pollution. The concentration of industrial activities, many of which depend on coal

as an energy source, stands out as a critical factor, since the combustion of coal produces significantly higher levels of pollutants when compared to other fossil sources (Zhao, 2021). At the same time, the progressive deterioration of car emissions further worsens air quality in urban centers (Moloney *et al.*, 2024). In contrast, rural areas, characterized by lower population density and less intense industrial activities, have substantially lower pollution levels. In addition to these differences, it should be noted that habits and lifestyles in these two types of environments are usually different. These discrepancies highlight the challenges of sustainable resource management and mitigating environmental impacts in the context of an urbanized society (Slezakova *et al.*, 2020; Gregório *et al.*, 2024; Soares *et al.*, 2024).

In addition to contextualizing air pollution, it is essential to identify the main pollutants that directly affect human health, especially in populations exposed to higher levels of physical exertion, namely football athletes (T.S. Filipe, *et al.*, 2013; Abelsohn & Stieb, 2024).

Considering the intensity of training and competitions, it is crucial to assess the levels of these pollutants in the environments frequented by athletes in order to understand the impacts on their performance and well-being (Campelli, 2020; Li *et al.*, 2021).

A crucial aspect of people's quality of life is regular physical activity. Its absence has been identified as the fourth biggest risk factor for global mortality, accounting for around 3.2 million deaths a year worldwide (WHO, 2012; Carlishe & Sharp, 2021). However, during physical exercise, physiological changes occur, such as increased lung ventilation, higher airflow velocity, increased respiratory rate and direct inhalation of air through the mouth. These changes increase the entry of air pollutants directly into the lungs and, consequently, into the bloodstream (Andrade *et al.*, 2021; de Carvalho *et al.*, 2020; Ferreira *et al.*, 2020; Ferreira *et al.*, 2021; Ferreira *et al.*, 2024a; Ferreira *et al.*, 2024b). For this reason, exercising in urban environments, especially during peak traffic hours, can pose increased health risks for exercisers, as pollutant levels reach high concentrations (Choi & Bum, 2020; Liu *et al.*, 2022).

However, the growing awareness of the importance of physical exercise in promoting health raises a relevant question: what is the impact of practicing physical activity in polluted environments? This contrast between the proven benefits of physical activity and the potential risks arising from exposure to adverse environmental conditions highlights the need for a more in-depth analysis of the effects of pollution in the context of physical exercise (Abelsohn & Stieb, 2024; Carlishe & Sharp, 2021).

Short-term exposure can aggravate pre-existing illnesses, which often results in a greater number of emergency room visits (APA, 2021). On the other hand, prolonged and repeated exposure to pollutants during exercise may be associated with the development of chronic diseases such as lung cancer, chronic bronchitis and pneumonia, as well as contributing to increased mortality from respiratory and cardiovascular causes (Donald & Boulet, 2008; Campelli, 2020; Huang, 2023; Liu *et al.*, 2022).

In this context, the role of public policies and legal instruments that guide the assessment and management of air quality, with a view to protecting public health, is essential. In Portugal, Decree-Law 102/2010 of September 23rd establishes the principles and criteria for monitoring ambient air quality, in accordance with the guidelines of the WHO and the EU (Diário da República, 2010).

By guaranteeing a structured air pollution monitoring system, this decree actively contributes to the achievement of various Sustainable Development Goals (SDG), such as promoting health and well-being (SDG 3), building safer and more resilient cities (SDG 11) and climate action (SDG 13) (UN News, 2024). It also raises public awareness of air quality and the risks associated with

its degradation, thus creating conditions for more informed and healthier choices - particularly relevant for those who practice physical activity in urban environments (Andrade *et al.*, 2021; Campelli, 2020).

With this in mind, the aim of this study was to assess the concentration of air pollutants and particles, namely CO, CO₂, VOC, PM_{2.5}, PM₁₀, ultrafine particles and the meteorological variables, temperature (T°) and relative humidity (Hr), existing in two different areas, an urban area, located in Taveiro, district of Coimbra, and a rural area, located in Souselo, district of Viseu, as well as analyzing the ambient air quality in these areas in order to investigate whether there are significant differences between them and to understand the impact on the athletes of the soccer clubs in these areas - Clube de Futebol União de Coimbra and Souselo Futebol Clube.

2. MATERIALS AND METHODS

This was an observational, descriptive, analytical, cross-sectional study. The study consisted of assessing the exposure of athletes from two football clubs, namely Souselo Futebol Clube and Clube de Futebol União de Coimbra, located in a rural area and an urban area.

The sample consisted of the two football fields where the respective training sessions take place and the 63 athletes and coaches who took part in the study. The sampling method used was non-probabilistic and the technique was one of convenience. The inclusion criteria for the study were: players and coaches belonging to the soccer clubs where the study was carried out.

Data collection was between January and March 2025 and consisted of two distinct stages. Firstly, the air was assessed by measuring the environmental parameters CO, CO₂, VOC, PM₁₀, PM_{2.5} and ultrafine particles and the meteorological variables T° and Hr at both soccer pitches of the clubs under study. The second stage consisted of administering a questionnaire to the players and coaches who were present at training sessions during the period in which the measurements took place.

With regard to the first stage of the investigation, the measurements were taken over a period of 30 minutes, with minute-by-minute sampling, before, during and after each training session at the clubs under study, in the afternoon on different days. To take the measurements, the equipment was placed at pitch-side, specifically near the players' benches (touchline area), at approximately the same height as the athletes' and coaches' airways (approx. 1.5 meters above ground). This position was chosen to represent the immediate breathing zone during training sessions at both clubs. It is important to note the distinct characteristics of the playing surfaces: the Souselo Futebol Clube (rural) facility features a synthetic turf pitch, whereas the Clube de Futebol União de Coimbra (urban) facility utilizes a natural grass pitch. With regard to the parameters VOC, CO, CO₂, T° and Hr, the equipment Q-Track™ Plus, brand TSI, model 8552/8554, was used to evaluate the concentrations of PM_{2.5}, PM₁₀, the equipment Particles Counters, brand Lighthouse Worldwide Solutions, model 3016 IAQ, to assess ultrafine particles we used the equipment P-Track Ultrafine Particle Counter, brand TSI, model 8525. The exposure limit value was considered to be 25 µg/m³ for PM_{2.5} and 50 µg/m³ for PM₁₀, as stated in Decree-Law no. 102/2010, of September 23.

With regard to the second phase of the research, the questionnaire was structured into four fundamental sections: the first dedicated to the sociodemographic characterization of the study participants; the second, to understanding the perception of air quality and health; the third, to analyzing the health condition of athletes and coaches; and finally, the fourth section dealt with active and healthy habits and lifestyles.

The data collected was statistically processed using IBM SPSS Statistics version 29.0. Descriptive statistics techniques were used, such as arithmetic mean, standard deviation, minimum and maximum, and frequency tables. In order to apply parametric or non-parametric tests, statistical measures of shape were used, such as asymmetry and kurtosis, as well as adherence to normal. With regard to the hypothesis tests applied, the following statistical tests were used: one-sample Student's t-test, Pearson's chi-square, Cohen's t-test for correlation and ANOVA with two fixed factors. The interpretation of the data was based on a significance level of $p \leq 0.05$ for a 95% confidence level.

3. RESULTS

The study sample included an assessment of the air quality in the football training facilities of the chosen clubs, as well as 63 athletes and coaches who played football at these clubs. Of the 63 individuals who took part in the study, 20 were female (31.3%) and 43 were male (68.7%). In terms of educational qualifications, 1.59% had completed the 2nd cycle of basic education (5th to 6th grade), 1 of whom was male, 3.17% had completed the 3rd cycle of basic education (7th to 9th grade), 2 of whom were female, 76, 19% had secondary education, 34 males and 14 females, 12.70% had a degree, 7 males and 1 female, and 6.35% had a Master's/PhD, 1 male and 3 females. As for where they lived, urban or rural, 74.0% lived in a rural area and 25.0% in an urban area. Regarding the area where they practiced physical exercise, 68.25% practiced in a club located in a rural area and 31.75% in a club located in an urban area.

Table 1 compares the estimated analytical values of the average concentrations of PM_{2.5}, PM₁₀, CO₂, Ultrafine Particles, VOC and the meteorological conditions T° and Rh recorded in both zones assessed with the legally established values.

Table 1: Comparison of air quality parameters between rural and urban areas.

Parameter		Mean	Standard Deviation	p-value
PM _{2.5} µg/m ³	Rural Area	10.0947	9.93065	< 0.05 ^b
	Urban Area	6.3428	5.02286	
PM ₁₀ µg/m ³	Rural Area	22.4924	20.22575	< 0.05 ^b
	Urban Area	17.7851	3.27118	
CO ₂ _ppm	Rural Area	390.58	29.880	< 0.05 ^a
	Urban Area	435.86	129.237	
UFP	Rural Area	14124.03	8195.280	< 0.05 ^a
	Urban Area	6877.79	5245.230	
VOC	Rural Area	0.00	0.053	< 0.05 ^b
	Urban Area	0.44	0.813	
T° (°C)	Rural Area	10.344	3.595	< 0.01 ^b
	Urban Area	11.998	4.54	
Rh (%)	Rural Area	69.426	1.683	< 0.01 ^a
	Urban Area	74.43	2.82	

T° = Temperature; Rh= Relative humidity; Levene's test for equality of variances.

Statistical tests: ^a1-factor ANOVA test and ^b Welch test

The results of the comparative analysis between the two locations showed statistically significant differences in air quality. While both areas remained within the legal limit values ($PM_{2.5}=25\mu g/m^3$ and $PM_{10}=50\mu g/m^3$), the rural area presented significantly higher concentrations of particulate matter compared to the urban area ($p < 0.05$). Was observed in the concentrations of CO_2 , ultrafine particles and VOC, whose values were higher in the urban area.

The next step was to analyse the temperature and relative humidity in both zones (Table 2).

Table 2: Comparison of the $PM_{2.5}$ and PM_{10} values obtained in the areas under study with the legally established exposure limit values.

Parameter	ELV ($\mu g/m^3$)	Area	Mean	SD	Percentile 25	Percentile 50	Percentile 70
$PM_{2.5}$	25	Urban	6.34	5.02	1.74	4.65	27.3
		Rural	10.10	9.93	4.77	6.87	12.3
PM_{10}	50	Urban	17.79	3.27	15.49	17.17	20.01
		Rural	22.49	20.23	8.9	12.44	12.36

ELV= Exposure limit value; SD= Standart Deviation; Cohen's T Correlation Test

Data in Table 2 indicates that average $PM_{2.5}$ concentrations in both urban ($6.34 \mu g/m^3$) and rural ($10.10 \mu g/m^3$) areas remained below the ELV. However, a critical finding emerges when analyzing the distribution: the 70th percentile in the urban area reached $27.3 \mu g/m^3$, exceeding the legally established limit. This reveals that despite a low overall average, athletes were subjected to acute periods of higher risk during specific training sessions. Regarding PM_{10} , although the rural area presented a higher average ($22.49 \mu g/m^3$) compared to the urban area ($17.79 \mu g/m^3$), the percentiles showed an asymmetrical distribution. Notably, the 70th percentile in the urban zone ($20.01 \mu g/m^3$) was higher than in the rural zone ($12.36 \mu g/m^3$), suggesting that urban environments are more prone to episodic pollution spikes even when mean values appear favorable.

Considering the four environmental parameters analyzed - CO_2 , $PM_{2.5}$, PM_{10} and Ultrafine Particles - we tried to assess whether they could show different behaviors depending on the geographical characteristics where the athletes trained, as well as the training period at their clubs. The interaction between geographical location and training periods was analyzed using a two-way ANOVA. The results, including mean values and standard deviations for each pollutant, are summarized in Table 3.

Table 3: Comparison of air quality parameters according to geographical characteristics

Parameter			Rural Area (N=121)	Urban Area (N=60)	Total (N=181)
CO_2	Before training	M $\pm$ SD	403.43 $\pm$ 37.04	389.52 $\pm$ 39.214	398.82 $\pm$ 38.23
	During training	M $\pm$ SD	390.12 $\pm$ 26.80	505.67 $\pm$ 191.759	428.85 $\pm$ 125.13
	After training	M $\pm$ SD	378.07 $\pm$ 16.47	412.40 $\pm$ 68.294	389.51 $\pm$ 44.51
	Total	M $\pm$ SD	390.57 $\pm$ 29.88	435.86 $\pm$ 129.237	405.67 $\pm$ 81.23

Parameter			Rural Area (N=121)	Urban Area (N=60)	Total (N=181)
PM _{2.5}	Before training	M ± SD	7.7180±2.85	7.09±5.603	7.510±3.97
	During training	M ± SD	7.423±4.22	7.10±5.566	7.315±4.69
	After training	M ± SD	15.141±15.27	4.84±3.273	11.706±13.50
	Total	M ± SD	10.095±9.93	6.34±5.023	8.844±8.78
PM ₁₀	Before training	M ± SD	16.98±9.98	19.092±2.55	17.682±8.34
	During training	M ± SD	16.17±7.84	16.621±3.34	16.322±6.67
	After training	M ± SD	34.32±29.34	17.643±3.42	28.758±25.26
	Total	M ± SD	22.49±20.226	17.785±3.27	20.923±16.76
UFP	Before training	M ± SD	1597.44±10901	5885.67±3801.11	12311.22±10224.8
	During training	M ± SD	13590.50±6469.57	7018.67±5121.98	11387.65±6791.2
	After training	M ± SD	13268.25±6191.69	7729.05±6405.37	11421.85±6772.5
	Total	M ± SD	14124.03±8195.28	6877.79±5245.23	11708.62±8096.9

M= Mean; SD= Standart Deviation; UFP= Ultrafine Particles; Statistical Test: ANOVA with 2 Fixed Factors.

There was a statistically significant interaction effect between training period and geographical location for all the parameters analyzed, influencing variations in environmental exposure levels. In the case of CO₂, the results indicated a significant interaction effect ($F_{(Per.training \times location)} = 32,441; gl_1 = 2; gl_2 = 534; p < 0,001; \eta_p^2 = 0,108$). For PM_{2.5}, the results indicated ($F_{(Per.training \times location)} = 19,607; gl_1 = 2; gl_2 = 534; p < 0,001; \eta_p^2 = 0,068$). The figure for PM₁₀ was ($F_{(Per.training \times location)} = 18,719; gl_1 = 2; gl_2 = 534; p < 0,001; \eta_p^2 = 0,066$). Finally, the interaction effect on ultrafine particles was also significant, although less so, with ($F_{(Per.training \times location)} = 3,355; gl_1 = 2; gl_2 = 534; p = 0,036; \eta_p^2 = 0,012$). In addition, the main effects of the fixed factors were also statistically significant. The training effect on CO₂ levels was significant, as was the location Effect ($F_{(Per.training)} = 27,349; gl_1 = 2; gl_2 = 534; p < 0,001; \eta_p^2 = 0,093; F_{(Location)} = 46,725; gl_1 = 1; gl_2 = 534; p < 0,001; \eta_p^2 = 0,080$). With regard to particulate matter, the result obtained for PM_{2.5} was: ($F_{(Per.training)} = 5,723; gl_1 = 2; gl_2 = 534; p = 0,003; \eta_p^2 = 0,021; F_{(Location)} = 25,667; gl_1 = 1; gl_2 = 534; p < 0,001; \eta_p^2 = 0,046$), and for PM₁₀ was as follows: ($F_{(Per.training)} = 18,719; gl_1 = 2; gl_2 = 534; p < 0,001; \eta_p^2 = 0,064; F_{(Location)} = 11,497; gl_1 = 1; gl_2 = 534; p < 0,001; \eta_p^2 = 0,021$). With regard to Ultrafine Particles, there was no significant effect of the training period, but the location had a statistically significant impact ($F_{(Per.training)} = 0,112; gl_1 = 2; gl_2 = 534; p = 0,894; \eta_p^2 = 0,000; F_{(Location)} = 117,546; gl_1 = 1; gl_2 = 534; p < 0,001; \eta_p^2 = 0,180$).

In view of the results obtained, the combined effects were analyzed using the Least Significant Difference (LSD) Multiple Comparisons test, with the support of the trajectory Figures below, in order to observe the patterns of variation in the different contexts (Figures 1, 2, 3 and 4).

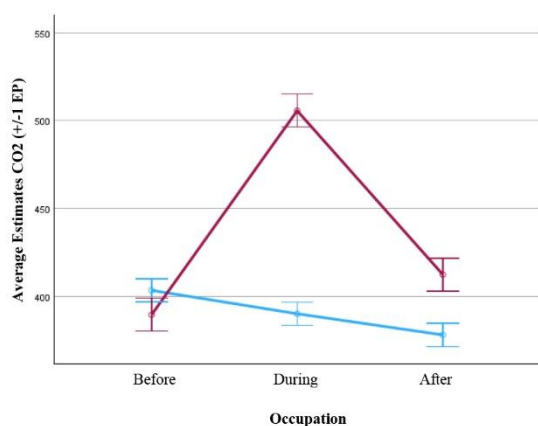


Figure 1: Estimated average CO₂ levels according to training period and geographical location

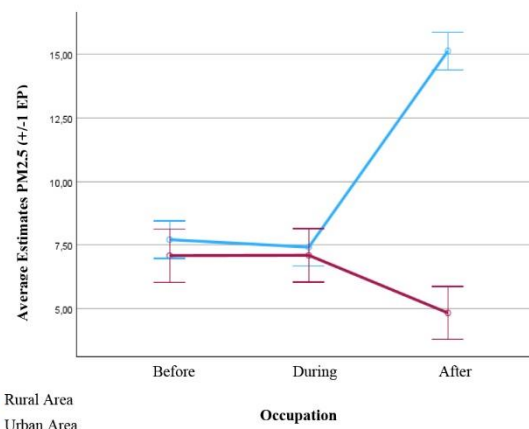


Figure 2: Estimated average PM_{2.5} levels according to training period and geographical location

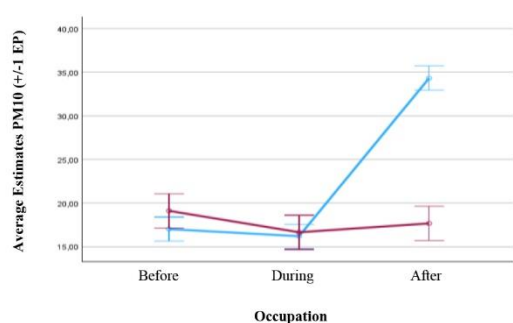


Figure 3: Estimated average PM₁₀ levels according to training period and geographical location

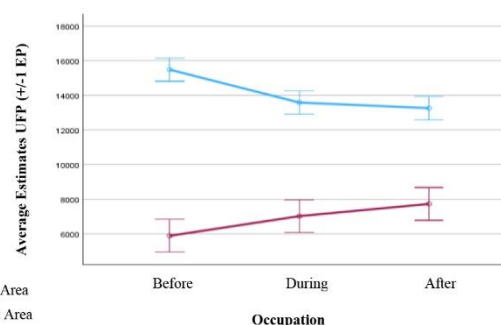


Figure 4: Estimated average UFP levels according to training period and geographical location

The next step was to assess the prevalence of symptoms/diseases self-reported by the study participants. The most common reported symptoms were sneezing attacks, runny or blocked noses (19.0%), headaches (12.7%) and asthma (11.1%). The remaining symptoms had much lower prevalence rates (< 8%).

In table 4, we tried to assess the relationship between symptoms/diseases and Area of Residence and Training Area.

Table 4: Relationship between reported symptoms/diseases and Home Zone and Training Zone

Symptoms/Diseases		Residence Area		Training Area	
		Rural Area	Urban Area	Rural Area	Urban Area
Asthma	Yes	6 (22.2%)	1 (11.1%)	6 (24%)	1 (9.1%)
	No	21 (77.8%)	8 (88.9%)	19 (76.0%)	10 (90.0%)
Dry Cough	Yes	4 (14.8%)	1 (11.1%)	4 (16%)	1 (9.1%)
	No	23 (85.2%)	8 (88.9%)	21 (84%)	10 (90.9%)

Symptoms/Diseases		Residence Area		Training Area	
		Rural Area	Urban Area	Rural Area	Urban Area
Bronchitis	No	23 (85.2%)	8 (88.9%)	21 (84.0%)	10 (90.9%)
	Yes	1 (3.7%)	0	1 (4%)	0
	No	26 (96.3%)	9 (100%)	24 (96.0%)	11 (100%)
Headache	Yes	6 (22.2%)	2 (22.2%)	7 (28.0%)	1 (9.1%)
	No	21 (77.8%)	7 (77.8%)	18 (72%)	10 (90.9%)
Allergic Rhinitis	Yes	1 (3.7%)	0	1 (4%)	0
	No	26 (96.3%)	9 (100%)	24 (96.0%)	11 (100%)
Torture	Yes	3 (11.1%)	0	3 (12.0%)	0
	No	24 (88.9%)	9 (100%)	22 (88.0%)	11 (100%)
Breathing Difficulties	Yes	2 (7.4%)	0	2 (8%)	0
	No	25 (92.6%)	9 (100%)	23 (92.0%)	11 (100%)
Sensitivity to odors	Yes	1(100%)	0	0	1 (9.1%)
	No	26 (96.3%)	9 (100%)	25 (100%)	10 (90.9%)
Sneezing, runny nose or blocked nose	Yes	9 (33.3%)	3 (33.3%)	6 (24.0%)	6 (54.5%)
	No	18 (66.7%)	6 (66.7%)	19 (76%)	5 (45.5%)
Irritation, burning or dry eyes	Yes	1 (3.7%)	1 (11.1%)	1 (4.0%)	1(9.1%)
	No	26 (96.3%)	8 (88.9%)	24 (96.0%)	10(90.9%)
Itching	Yes	1 (3.7%)	1 (11.1%)	1(4.0%)	1(9.1%)
	No	26 (96.3%)	8 (88.9%)	24 (96.0%)	10(90.9%)

The distribution of health symptoms and diseases among athletes and coaches, according to their residence and training environments, is summarized in table 4. Contrary to expectations for urban centers, a higher prevalence of several respiratory and systemic symptoms was observed among participants who live or train in rural areas. Specifically, nasal symptoms (sneezing, runny, or blocked nose) were reported by 33.3% of those in rural training zones. Notably, the prevalence of asthma was also higher in the rural group, affecting 22.2% of residents and 24% of those training in these areas.

Regarding seasonal influence, 57.1% of respondents perceived an exacerbation of symptoms during specific times of the year. Winter was identified as the most critical season for symptom intensification (23.9%), followed by spring (17.5%) and summer (12.7%), while autumn showed the lowest impact (3.2%). These findings suggest that the specific environmental conditions of

the rural sites studied, potentially linked to the high UFP levels previously noted, may play a significant role in the athletes' respiratory health.

Table 5 shows the distribution of the presence and absence of symptoms or illnesses mentioned by the participants, according to the seasons.

Table 5: Relationship between symptoms/diseases and the season of the year (winter, spring, fall or summer) in which they tended to worsen.

Symptoms/Diseases	Worsening	Winter	Autumn	Spring	Summer
Asthma	Yes	0	0	4 (36.4%)	1(25.0%)
	No	9 (100%)	2 (100%)	7 (63.6%)	3 (75%)
Dry Cough	Yes	1 (11.1%)	0	1 (9.1%)	2 (50%)
	No	8 (88.9%)	2 (100%)	10 (90.9%)	2 (50%)
Bronchitis	Yes	0	0	1 (9.1%)	0
	No	9 (100%)	2 (100%)	10 (90.9%)	4(100%)
Headache	Yes	4 (44.4%)	1 (50%)	0	2 (50%)
	No	5	1 (50%)	11 (100%)	2 (50%)
Allergic Rhinitis	Yes	0	0	0	0
	No	9 (100%)	2 (100%)	11(100%)	4(100%)
Torture	Yes	1 (11.1%)	1 (50%)	0	1 (25%)
	No	8 (88.9%)	1(50%)	11 (100%)	3 (75%)
Breathing Difficulties	Yes	0	0	0	1 (25%)
	No	9 (100%)	2 (100%)	11 (100%)	3 (75%)
Sensitivity to odors	Yes	0	0	0	1 (25%)
	No	9 (100%)	2 (100%)	11	3 (75%)
Sneezing, runny nose or blocked nose	Yes	3 (33.3%)	1 (50%)	7 (63.6%)	1 (25%)
	No	6(66.7%)	1(50%)	4 (36.4%)	3 (75%)
Irritation, burning or dry eyes	Yes	1 (11.10%)	0	0	1 (25%)
	No	8 (88.9%)	2 (100%)	11 (100%)	3 (75%)
Itching	Yes	1 (11.1%)	0	0	1 (25%)
	No	8 (88.9%)	2 (100%)	11 (100%)	3 (75%)

With regard to the symptoms with the highest number of affirmative responses regarding seasonal worsening, the symptom “Sneezing, runny nose or stuffy nose” stands out. Spring was the most frequently mentioned season (63.6%). The symptom “Headache” was mentioned by 5 respondents, while winter was mentioned by 4 (44.4%). In the case of “Asthma”, 4 participants reported worsening, of which 36.4% indicated spring and 25% summer. For the remaining symptoms, the number of affirmative responses was low.

4. DISCUSSION

Air pollution is not only an environmental problem, but also a social one, given the complexity of the interactions between various pollutants in the atmosphere. (Maria & Silva, 2017).

The results obtained in this study allow for an in-depth reflection on the impact of air quality on the health of athletes, considering disparate geographical contexts (urban vs. rural) as well as environmental (air quality and meteorological parameters).

Contrary to initial expectations, the rural area was found to have higher concentrations of various pollutants, namely PM_{2.5}, PM₁₀, Ultrafine Particles and CO₂. This finding corroborates the results of recent studies highlighting specific pollution sources in rural areas, such as biomass burning, unpaved roads and agricultural practices, which can contribute significantly to air pollution, even in low population density environments. The analysis of air pollutants revealed distinct variations both when considered in isolation and in combination. When analyzed independently, the type of zone revealed differences in the concentrations of the various pollutants, confirming that geographical factors influence environmental exposure (Reche *et al.*, 2020; Huang, 2023). On the other hand, the time of physical activity (before, during and after training) was also associated with specific fluctuations, particularly in inhalable particles (PM_{2.5} and PM₁₀), reflecting the influence of physical exertion on ventilation dynamics and the absorption of pollutants (Andrade *et al.*, 2021; Abelsohn & Stieb, 2024). However, it was in the combined analysis - which crossed the variables location and training time - that more complex patterns emerged, revealing interactions that amplify exposure in certain contexts, especially when exercise is carried out in environments with a higher concentration of pollutants, reinforcing the need to simultaneously consider the space and time of exposure when assessing environmental risk in sports contexts, given that the interaction between factors can worsen the impact on respiratory health (Liu *et al.*, 2022; WHO, 2024). In addition, it is important to consider the type of surface on training pitches as a factor that modulates environmental exposure. Synthetic turf surfaces, especially those that are rubber-based, have been associated with the release of ultrafine particles, especially when subjected to intense friction or high temperatures. Studies indicate that these surfaces can reach significantly higher temperatures than natural turf, which, in addition to contributing to the thermal discomfort of players, increases the emission of volatile pollutants and suspended particles (Slezakova *et al.*, 2020).

Although all the concentrations were within the legally established limit values, it is important to note that continuous exposure to moderate concentrations of air pollutants can trigger adverse effects, such as inflammation of the respiratory tract, aggravation of chronic diseases and allergic manifestations. In this study, the most commonly reported symptoms among the participants were sneezing attacks, headaches, dry coughs and asthma, with a higher incidence among those who trained in urban environments. This data may be related to the greater presence of road traffic, the concentration of suspended particles and simultaneous exposure to multiple pollutants. Scientific literature has warned of the asymptomatic effects of air pollution, especially in groups exposed to high levels of physical exertion, such as athletes, who during exercise increase their respiratory

rate and ventilation depth, facilitating the entry of pollutants into the lung alveoli, such as PM_{2.5} and PM₁₀ (Andrade *et al.*, 2021; Abelsohn & Sieb, 2024).

At the same time, weather conditions also influenced the prevalence of symptoms reported. The analysis showed that lower temperatures and moderate to high levels of relative humidity were associated with greater discomfort and manifestation of respiratory symptoms, in line with the evidence that cold and humid environments favor irritation of the airways and aggravate allergic and respiratory symptoms (Donald & Boulet, 2008). Seasonality also revealed an important pattern, with winter and spring standing out as periods of greater symptomatic aggravation, possibly due to the combination of high concentrations of pollutants, increased levels of pollen and the prevalence of viral respiratory infections (WHO, 2024; Liu *et al.*, 2022).

In addition, it is important to mention the potential cumulative and unnoticeable effects of prolonged exposure to pollutants, even in moderate concentrations. Several studies point to the existence of silent physiological changes, such as chronic low-grade inflammation, endothelial dysfunction and oxidative stress, which can compromise long-term health and reduce the physical performance of athletes (Liu *et al.*, 2022; Huang, 2023; Reche *et al.*, 2020).

The higher prevalence of respiratory and systemic symptoms in the rural area aligns with the environmental data previously discussed. Although mean concentrations were within legal limits, the rural facility (Souselo Futebol Clube), characterized by synthetic turf, exhibited significantly higher levels of ultrafine particles (UFP) and pronounced peaks of PM₁₀ following training sessions. The physical nature of synthetic grass, combined with the resuspension of particles during athletic activity, may contribute to the increased reports of asthma (24%) and nasal symptoms (33.3%) among those training in this environment. These results suggest that the specific characteristics of the playing surface and the localized air quality dynamics in the rural zone pose a greater challenge to the athletes' respiratory health than the typical urban background levels observed at the União facility.

5. CONCLUSIONS

This research has provided a deeper understanding of the impact of air quality on the respiratory health and well-being of athletes who train in different geographical contexts - rural and urban. The results obtained show statistically significant differences in the levels of air pollutants between the two areas, with, unexpectedly, the highest concentrations of PM_{2.5}, PM₁₀, Ultrafine Particles and CO₂ being recorded in the rural area. This contradicts the common perception that urban areas are intrinsically more polluted and raises relevant questions about the role of local emission sources in less urbanized areas, namely agricultural practices, burning or lack of paving. In addition to pollutants, meteorological variables such as temperature and relative humidity have been shown to influence environmental comfort and the prevalence of symptoms. Cold environments with high humidity were identified as more uncomfortable and associated with greater symptomatic aggravation, in line with the literature which identifies these factors as potentiators of airway irritation and allergic conditions. The influence of seasonality was also evident, with winter and spring being the season's most associated with worsening symptoms, possibly due to the combination of pollutants, pollen and respiratory infections typical of these seasons.

This highlights the importance of integrating environmental monitoring systems into sports venues, as well as raising awareness among athletes, coaches and sports institutions. An informed choice of training times and locations, depending on atmospheric conditions and pollution levels, could be an effective strategy for reducing exposure and the associated risks. It is also important

to acknowledge some limitations associated with this study, which may affect the generalizability of the results obtained. Data was only collected from two soccer clubs, which limited the diversity of contexts and reduced the sample size. In addition, the athletes' adherence to and completion of the questionnaire proved to be challenging, with the need for constant reinforcement of the importance of their contribution, which may have influenced the quality and depth of some of the answers they gave. Despite these obstacles, the sample collected made it possible to meet the proposed objectives and produce statistically significant and relevant results.

This research is a contribution to consolidating knowledge on the interface between environmental health and sports practice. By integrating environmental variables, individual perceptions and clinical symptoms into the same analysis model, the study offers a multidimensional perspective on the risks of air pollution in sports contexts. This type of approach is proving to be increasingly pertinent, not only to guide public health measures, but also in the organization of sports settings.

In short, it is recommended that future research include a longitudinal assessment of athletes' respiratory health, as well as expanding the sample and diversifying the geographical and sporting contexts analyzed. The integration of physiological indicators, such as spirometry or inflammation biomarkers, could also contribute to a more robust analysis of the effects of air pollution on the performance and health of physical activity practitioners.

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