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Playing for breath: How particulate pollution affects cardiorespiratory performance in youth soccer under the "cleaner air, better game" initiative

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Abstract

The UEFA campaign "Cleaner Air, Better Game" initiated in 2021 highlights the detrimental effects of particulate pollution on cardiorespiratory fitness and overall performance in soccer players. This study examined variations in maximal oxygen uptake ($\dot{V}O_2$max) among 92 young soccer players from two villages with differing pollution levels. Utilizing a longitudinal design with pre- and post-exposure measurements, participants were divided into an experimental group (EG, $n = 46$) from a polluted area and a control group (CG, $n = 46$) from a cleaner environment. Evaluations were conducted using the Yo-Yo Intermittent Recovery Test to determine $\dot{V}O_2$max. The EG exhibited a significant improvement of 12.35% in $\dot{V}O_2$max compared to 1.97% in the CG, with statistical significance at $p < 0.001$. Initial $\dot{V}O_2$max levels were lower in the EG ($t = 2.589$; $p < 0.05$), but post-test values surpassed those of the CG ($t = -3.380$; $p < 0.01$). These findings suggest that high particulate pollution adversely impacts $\dot{V}O_2$max in young soccer players. Future research should explore long-term effects of air quality on athletic performance and develop strategies to mitigate pollution exposure during training.

Keywords

Association football, maximal oxygen uptake, training environment, Yo-Yo Intermittent Recovery test

Introduction

Air pollution can be defined as the presence of either gases or particles originating from direct sources formed in the atmosphere.[1] Air pollution is estimated to contribute to approximately 8.8 million deaths worldwide each year. It consists of various pollutants, including gaseous emissions such as sulfur dioxide (SO_2), ozone (O_3), and nitrogen dioxide (NO_2), as well as particulate matter classified as PM_{10} and $PM_{2.5}$. These pollutants are significant contributors to reduced life expectancy, the onset of numerous health conditions, and a decline in overall quality of life.[2] In the specific case of athletes, the inhalation of high concentrations of air pollution can be associated with ST-segment depression during exercise,[3–5] while increasing blood pressure,[6] decreasing airflow[7] and increasing pulmonary inflammation.[6]

Sports such as soccer demand high levels of cardiorespiratory fitness.[8] Professional soccer players can run up to 14 kilometers per match,[9] while young players typically cover 10 to 12 kilometers.[10] Since running demands vary from low to maximal intensity, measures such as maximal oxygen uptake are vital for physical performance.[11] However, one of the consequences for populations exposed to air pollution is the negative impact on

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maximal oxygen uptake. For example, children exposed to significant levels of PM_{10} exhibit lower levels of maximal oxygen uptake and cardiorespiratory fitness.[4,5] Additionally, marathon athletes perform significantly worse while exposed to higher PM_{10} levels.[12] Each 17-ppb increase in atmospheric ozone is associated with a reduction in aerobic fitness by up to 1.52%.[13] Moreover, ozone can cause an immediate negative effect on maximal exercise time, workload, oxygen consumption, and performance.[14] These findings point to a concerning trend whereby young soccer players, whose respiratory systems are still in development, may be particularly vulnerable to performance impairments linked to environmental conditions.[15] Indeed, in soccer, elevated air pollution has been associated with significant reductions in total distance covered and high-intensity efforts when compared to performances under cleaner air conditions.[16]

As mentioned above, previous research has explored the impact of air quality—particularly three specific pollutants: ozone, particulate matter, and nitrogen dioxide—on the physical performance of soccer players. By analyzing an extensive dataset comprising 8927 individual match observations from 461 players in the German Bundesliga across the 2017/2018 and 2018/2019 seasons, the study identified a clear pattern: higher levels of air pollution were linked to notable decreases in both total distances covered and high-intensity actions among professional players. These results highlight that even marginal increases in air pollution can negatively influence athletic performance, underscoring the urgent need for strategies aimed at improving air quality during both training and competitive fixtures. Enhancing environmental conditions can substantially benefit athletes' health and performance, promoting overall well-being on the pitch.

In addition, studies have shown that elevated PM_{10} levels result in significant reductions in physical performance,[15] with pollution particularly affecting players' health and aerobic capacity during evening and winter matches.[17]

However, most existing research has focused on adult populations or has offered only limited insights in terms of age. Studies specifically addressing young soccer players remain scarce, limiting our understanding of how early exposure to pollution might influence long-term athletic development and health. Furthermore, there is a lack of comprehensive data comparing the effects of different pollution sources on key performance metrics in sport. Despite existing research on the acute effects of air pollution on match performance, the implications for $\dot{V}O_2max$ in soccer players remain underexplored. Understanding medium and long-term adaptations to air quality is crucial for informing coaches and health professionals. In this context, UEFA launched the campaign "Cleaner Air, Better Game",[18] which aims to mitigate the adverse effects of air pollution on young soccer players, while promoting clean air as a fundamental element of sustainable practice within the sport. This initiative is closely aligned with the broader UEFA soccer Sustainability Strategy, which seeks to raise environmental awareness throughout the soccer community. The campaign endeavors to highlight the harmful consequences of air pollution and to encourage the adoption of effective measures to create healthier sporting environments, reinforcing UEFA's ongoing commitment to reducing its carbon footprint.

Against this backdrop, the present study aims to examine variations in $\dot{V}O_2max$ among young soccer players from two villages exposed to differing levels of particulate pollution. By conducting pre- and post-test assessments across multiple seasons, this research seeks to elucidate the relationship between air quality and aerobic performance. The findings have the potential to meaningfully inform future interventions and enhance the impact of initiatives such as UEFA's campaign, ultimately contributing to improved health and performance outcomes for young athletes.

Study area and methods

Participants and study area

A total of 92 young soccer players participated in this study, who were categorized them into two distinct groups: the Control Group (CG) consisting of 46 players (age: 11.18 ± 1.60 years; height: 148.02 ± 12.85 cm; body mass: 44.68 ± 12.03 kg; body mass index: 20.15 ± 3.71 kg/m^2) and the Experimental Group (EG) comprising 46 players (age: 11.67 ± 1.67 years; height: 148.71 ± 10.82 cm; body mass: 45.73 ± 10.67 kg; body mass index: 20.50 ± 3.22 kg/m^2). The two groups were drawn from two comparable villages located in southern Spain (Figure 1), specifically in the Andalusian region, which contains the largest olive grove area in the Mediterranean. This area covers approximately 1.5 million hectares, of which the two villages represent around 0.57 million hectares (Sánchez de la Campa et al., 2018). A priori sample size calculation was performed using the free online tool G*Power (www.gpower.hhu.de; accessed on 24 March 2025). The calculation targeted a statistical power of 95% and a significance level (α) of 0.05, based on data from previous research and similar studies.[19] The results indicated that a sample size exceeding 15 participants would be sufficient for the planned analysis.

In addition to preliminary interviews conducted with participants regarding their sporting activities and health status, specific inclusion and exclusion criteria were established to ensure the reliability and validity of the study outcomes. Participants were eligible if they met the following criteria: (i) provided informed consent to participate in the study; (ii) absence of chronic health conditions or pathologies that might influence physical performance; (iii) active registration with a valid federation license; and (iv) full participation in all training sessions throughout the

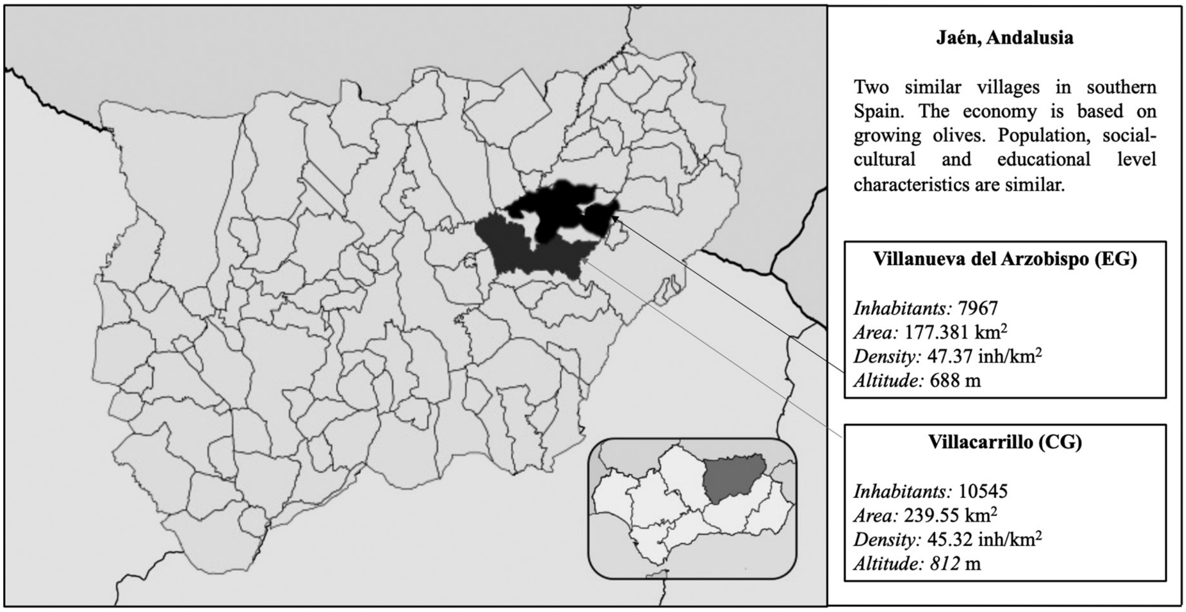

Figure 1. Distribution of Villanueva del Arzobispo (EG) and Villacarrillo (CG) in Andalusia, Spain (Europe).

intervention period. These criteria were designed to ensure a homogeneous sample and to minimize confounding variables that could affect the results of the Yo-Yo test. All selected participants met the inclusion criteria, thereby reinforcing the integrity of the study. In addition, all players were matched in terms of competitive level and category. Further information about the teams and categories can be found at https://www.rfaf.es.

Study design and data

A longitudinal study design was employed, incorporating pre- and post-exposure measurements of environmental pollution levels. This research was conducted from January to April 2022, a timeframe characterized by fluctuations in particulate pollution. The young soccer players were allocated using a convenience sampling approach: the EG, which was located in an area with particulate pollution, and the CG, situated in a region with lower levels of particulate pollution.

To assess the impact of pollution on the cardiorespiratory fitness of the participants, both groups were monitored to ensure they maintained their regular training routines (as described in the Training Program section). Data on particulate pollution were obtained from the Andalusian Regional Government's Environmental portal. Measurements were taken from a station that monitored both gaseous pollutants (including sulfur dioxide (SO_2), ozone (O_3), and nitrogen dioxide (NO_2)) and particulate matter (specifically PM_{10} and $PM_{2.5}$). Further details are available at: https://www.juntadeandalucia.es/medioambiente/portal/home.

The two villages, located 9.4 km apart, were comparable in terms of demographic, sociocultural, and educational characteristics. The dataset collected from the two locations included variables such as age, weight, height, and estimated maximal oxygen uptake ($\dot{V}O_2max$). Figure 2 provides additional details regarding the study timeline.

During the period 2005–2006, the village in the Experimental Group (EG) experienced exceedances of the daily limit for particulate matter less than 10 microns (PM_{10}), which poses risks to human health. In response, the Andalusian Regional Government implemented the Improvement, Control, and Monitoring Plan for air quality in Villanueva del Arzobispo (Jaén) through Decree 334/2010, issued on July 13. This plan included measures aimed at regulating both emission and immission levels, relocating the pomace oil extraction industry, and reducing the operational output and emissions of energy production facilities. These industrial interventions were executed between 2008 and 2009 and resulted in significant improvements in air quality, particularly in reducing PM_{10} concentrations.

However, from 2012 to 2013, there was a resurgence in PM_{10} levels within the municipality. Source characterization studies indicated that the primary contributors to these elevated particulate matter levels were biomass combustion processes in domestic heating systems, which tend to produce higher emissions during the colder months. Furthermore, an inventory conducted in 2018 revealed that low-quality olive wood and olive pits were being utilized in outdated heating technologies, leading to increased emissions. The geographical and climatic conditions of the area hinder the

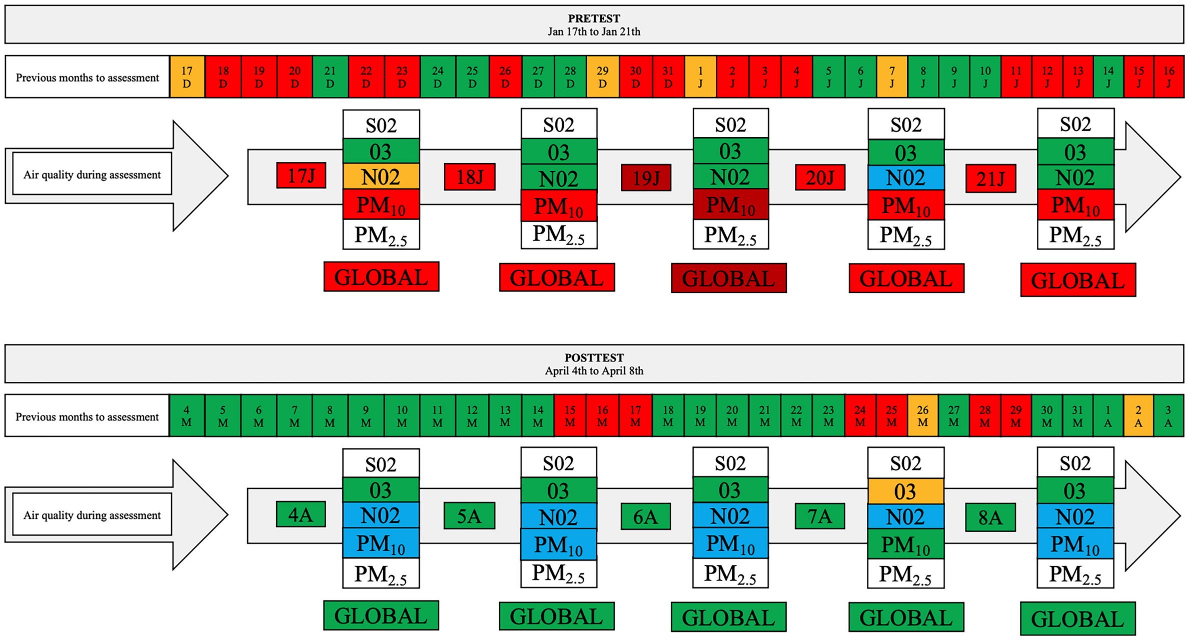

Figure 2. Distribution of EG and CG in Andalusia, Spain (Europe). Note: D: December; J: January; M: March; A: April; S02: Sulfur dioxide; 03: Ozone; N02: Nitrogen Dioxide; PM_{10}: Particulate matter of 10 microns; $PM_{2.5}$: Particulate matter of 2.5 microns. Air quality scale: Not appear (white,0), Good (blue,1), reasonably good (green,2), regular (yellow,3), unfavorable (red,4), very unfavorable (brown,5), extremely unfavorable (purple,6). Values obtained of: https://ws041.juntadeandalucia.es/pentaho/api/repos/%3Apublic%3ACalidad_Aire%3ACalidad_Aire.wcdf/generatedContent.

dispersion of this pollution, creating additional challenges for air quality management (see Figure 3).

In addition to the studies on source contributions, a comprehensive analysis was conducted to evaluate the pollution levels as part of the development of the Andalusian Strategy for Air Quality. This assessment focused on identifying the factors leading to exceedances of permissible pollution levels and exploring potential measures for improvement. A significant contributor identified was the combustion of solid biomass in both domestic and commercial heating systems.

Based on the findings of this analysis, a short-term Action Plan was developed to enhance air quality in Villanueva del Arzobispo and its surrounding areas, with the objective of implementing measures to promptly reduce particulate matter levels. This Action Plan received approval from the Regional Minister of Agriculture, Livestock, Fisheries, and Sustainable Development on April 30, 2019.

The plan encompasses several key objectives: i) to ensure compliance with the standards set forth in Directive 2008/50/EC of the European Parliament and Council, dated May 21, 2008, regarding ambient air quality and a cleaner atmosphere, as well as adherence to the provisions of Royal Decree 102/2011, dated January 28, concerning short-term action plans; ii) to proactively address potential exceedances of limit values by implementing immediate and temporary measures aimed at reducing PM_{10} levels, thereby mitigating the risk of surpassing legal thresholds; iii) to establish a strategic framework for action that focuses on three main areas: reducing emissions, promoting the adoption of more efficient and environmentally friendly heating systems, and implementing a communication strategy to inform and engage the residents of Villanueva del Arzobispo and the surrounding region.

Procedures

Data for the study were collected from two youth soccer teams in each group (CG and EG). Initial contact was made following an agreement with the management of the respective clubs to seek their participation. The legal guardians or parents of the players were informed about the study's objectives and procedures, and they subsequently provided informed consent by signing a form that outlined the associated risks and benefits of participation.

Participants' confidentiality was maintained in accordance with the guidelines set forth by the American Psychological Association. Furthermore, the study adhered to the ethical principles outlined in the Declaration of Helsinki for research involving human subjects, having received prior approval from the university's research ethics committee (code: 2021/89).

The principal investigator convened a meeting with the coaches of the clubs to clarify the measurement protocol. Cardiorespiratory fitness was assessed using the Yo-Yo test, ensuring consistency in structure, timing, and initial

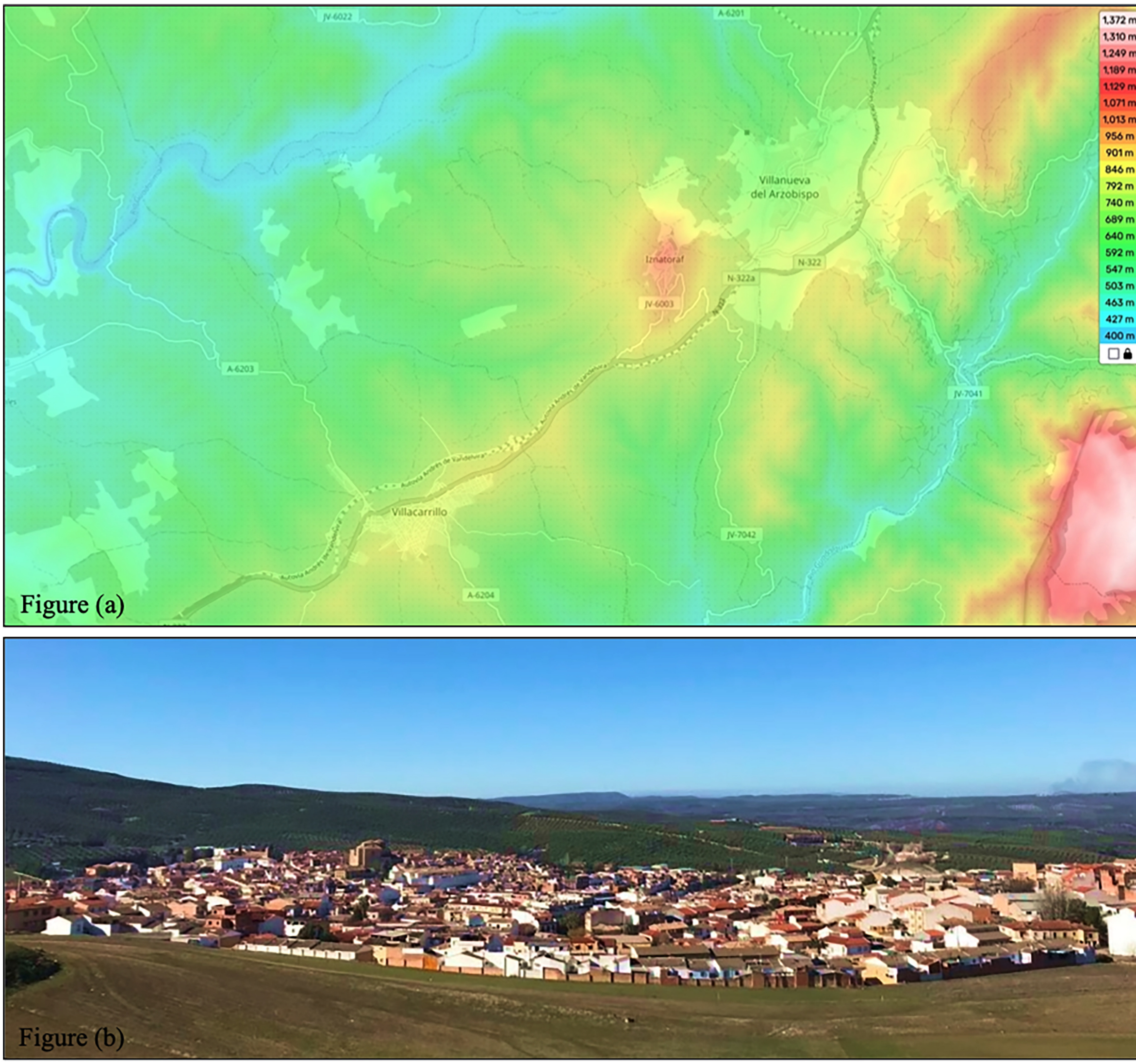

Figure 3. Characteristics of the studied villages. a. Altitude of both villages (EG and CG) in Andalusia (Spain) Figure reproduced from: https://es-es.topographic-map.com/map-ghh14/Villanueva-del-Arzobispo/. b. EG village (with particulate pollution).

instructions. The measurement process was thoroughly explained to the players in advance, addressing any questions queries or concerns raised by participants. The Yo-Yo test was conducted on the soccer field where the teams typically trained, utilizing the players' regular training equipment.

Measures

Anthropometry

Height, body weight, and body mass index (BMI) were recorded during pre- and post-measurement sessions, conducted at the same time and day of the week. Height was measured using a stadiometer (SECA 213, Birmingham, UK) to the nearest 0.1 cm, with participants instructed to remove their shoes and any items that could affect the measurement. Players were required to stand upright and still, with their arms positioned alongside their bodies and their gaze directed straight ahead. For each measurement, three readings were taken, and the most accurate value was selected. Weight and BMI were assessed using a TANITA scale (InnerScan BC-731, Arlington Heights, Illinois, USA).

Yo-Yo intermittent recovery test

The Yo-Yo Intermittent Recovery Level 1 (IR1) test involved a series of 20-meter shuttle runs back and forth between two markers, with the running speed progressively increasing as dictated by an audio playback. After each 40-meter run, participants were allowed a recovery period of 10 s, during which they performed light jogging (shuttle runs of 2 × 5 meters). The test commenced at a speed of 10 km/h for Level 1 and 13 km/h for Level 2, with both levels gradually increasing in speed throughout the duration of the test. The assessment concluded when a participant either reached voluntary exhaustion or was unable to maintain the required running speed in sync with the audio cues. At the end of the test, the total number of completed levels and shuttles, along with the overall distance covered (in meters), were recorded. Maximal oxygen uptake ($\dot{V}O_2$max, expressed in mL/min/kg) was estimated using the following formula[20].

$$\dot{V}O_2 \max = \text{final distance}(m) \times 0.0084 + 36.4.$$

Training program

In this observational study, the researchers did not exert any influence over the training dynamics, plans, or schedules of the participants. However, information was gathered from the coaches to characterize the players' exposure to the training regimen. The young soccer players involved in the study typically trained twice a week for 90 min per session and participated in one match each week. Both the EG and CG groups competed within the same category. The training program focused on enhancing overall physical fitness, including cardiorespiratory capacity, muscular strength and power, speed, and agility, as well as developing tactical and technical skills. The initial portion of each training session was dedicated to improving these general fitness attributes, while the latter part concentrated on tactical understanding and technical skills applied in game-like scenarios. Details of the training sessions have been previously documented.[21]

Statistical procedures

Data are expressed as mean ± standard deviation (SD) or as percentages. The normality of data distribution and homogeneity of variances were assessed using the Kolmogorov–Smirnov test (for samples greater than 50) and Levene's test, respectively. A paired sample t-test was employed to identify differences within the same group (Experimental Group [EG] or Control Group [CG]) through repeated measures analysis (pre- and post-test), as well as to compare differences between the two groups at baseline (pre-test) and at the second measurement (post-test). The significance threshold was established at 5% ($p < 0.05$). Correlations were calculated using the Pearson correlation coefficient (r), and ES (effect sizes, *d*) were determined using Cohen's *d*.[22] The interpretation of the ES, irrespective of its sign, adhered to the following scale: very small (0.01), small (0.20), medium (0.50), large (0.80), very large (1.20), and huge (2.0), as initially proposed by Cohen and later expanded by Savilowsky.[23] All statistical analyses were conducted using SPSS version 26 (SPSS Inc., Chicago, IL, USA).

Results

Descriptive statistics were calculated for both groups (CG and EG). These included the percentage change between pre- and post-tests, results from paired-sample t-test results (t-scores and *p*-values), and effect sizes. The findings are presented in Table 1 and illustrated in Figure 4.

The highest percentage difference between all possible comparisons and pre-post-tests was found within the EG (12.35% *vs.* 1.97% in CG), which was statistically significant (p <.001), with an ES of 1.38—classified as between very large and huge. Additionally, this was the only significant correlation observed within the EG (p <.001; Figure 4 and Table 1). Baseline $\dot{V}O_2$max values were lower among soccer layer in the EG village compared to CG players ([t] 2.589; $p < 0.05$). However, the post-test values were higher in EG players compared to CG ([t]-3.380; $p < 0.01$) (Figure 2). No additional significant differences or correlations were observed.

Discussion

This study investigated variations in $\dot{V}O_2$max among young soccer players from two villages with differing levels of particulate pollution, assessed at two distinct times of the year. The findings indicated that the group with higher prior exposure to elevated particulate pollution demonstrated a significant improvement in $\dot{V}O_2$max when their exposure was reduced. $\dot{V}O_2$max is widely recognized in the scientific literature as a critical indicator of match fitness, which can inform subsequent training sessions aimed at enhancing performance in young soccer players.[11] In contrast, the CG showed no significant differences between the two assessment periods. Furthermore, the EG exhibited significantly lower $\dot{V}O_2$max levels in the pre-test, aligning with previously reported data from the German Bundesliga.[16] Similarly, Lichter, Pestel, and Sommer found that variations in players' exposure to air pollution, influenced by match scheduling, adversely affected their productivity, as measured by the total number of passes made during matches.[15]

The results of this study corroborate earlier research suggesting that children exposed to high levels of PM_{10} tend to have lower $\dot{V}O_2$max and cardiorespiratory fitness.[4,5] Consequently, reductions in pollution levels are likely to lead to improvements in fitness, as the absence of physiological stressors during exercise enhances cardiorespiratory function. Additionally, it has been observed that each 17-ppb increase in atmospheric ozone correlates with a reduction in aerobic fitness of up to 1.52%.[13]

The findings of the current study align with previous research conducted on healthy populations, which indicated that prolonged exposure to particulate matter is negatively

Table 1. Descriptive statistics pre-test and post-test in control and experimental group.

Estimated $\dot{V}O_2$ max								
	Control Group (CG) ($n = 46$)				Experimental Group (EG) ($n = 46$)			
	Pre-test	Post-test	*t*-test	Pearson *r*	Pre-test	Post-test	%Dif	Pearson *r*
Estimated $\dot{V}O_2$ max **(ml/kg/min)**	41.16 ± 3.85	41.73 ± 4.14	(t)-0.814 (n.s)	.284 (n.s)	39.48 ± 3.09	44.27 ± 3.48	(t)-12.327***	.683***

Note: r = Pearson correlation coefficient; Significance level: n.s (no significant); *$p < .05$; **$p < .01$; ***$p < .001$. Data presented as mean ± SD.

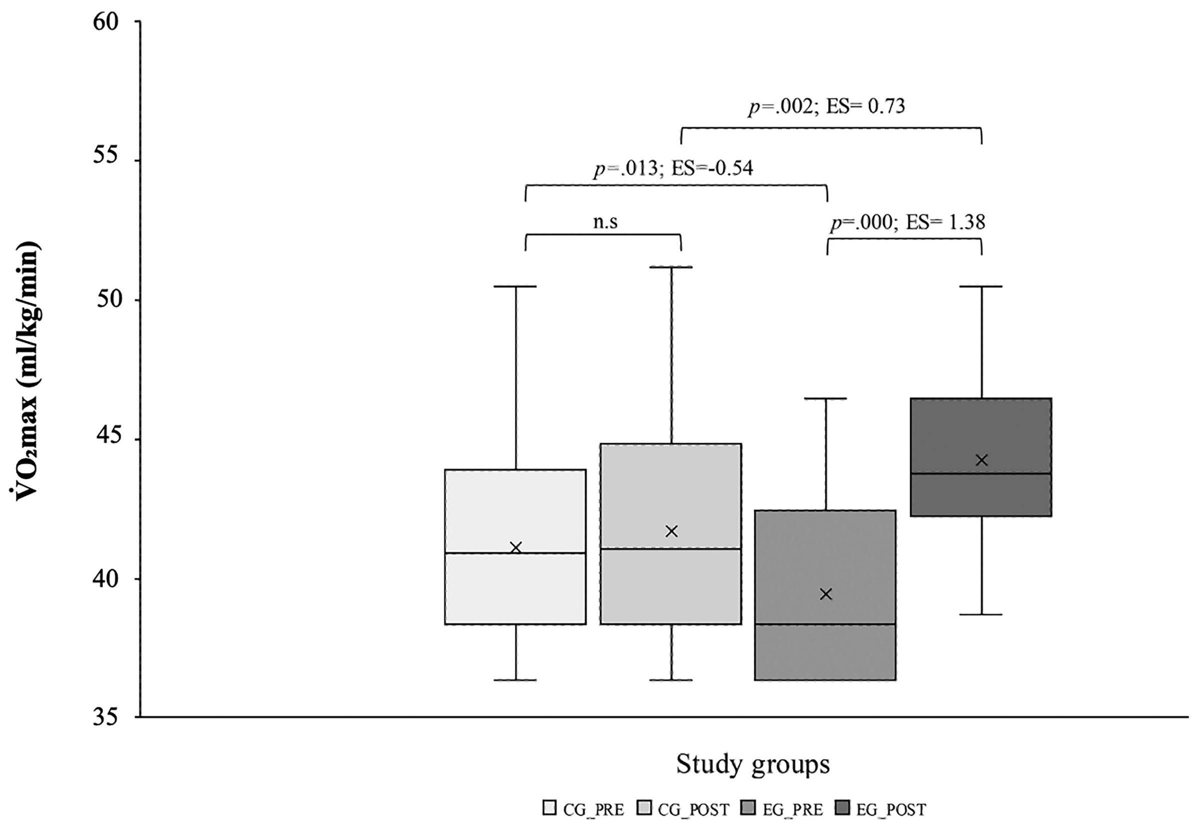

Figure 4. Box plots of estimated $\dot{V}O_2$ max pre-post-test for the experimental and control groups.

correlated with estimated maximal oxygen consumption.[5,24] This body of research is further supported by the work of Rundell and Caviston,[19] who observed a decline in exercise performance among fifteen healthy college-aged men. The EG in this study is situated in an area surrounded by millions of olive trees and has experienced numerous days with PM_{10} levels exceeding safe limits, potentially leading to significant health issues related to cardiorespiratory function.[25]

Exposure to air pollution can result in long-term oxidative stress and inflammation within the cardiovascular system[26] and may temporarily impair cognitive functions, thereby affecting decision-making processes.[27] This impairment can negatively influence passing accuracy[15] and, importantly, detract from overall physical performance, as highlighted in UEFA's "Cleaner Air, Better Game" campaign.[18] Additionally, research by Heyes, Neidell, and Saberian demonstrated a relationship between elevated pollution levels and adverse effects on sports performance.[28] This study specifically focuses on the impact of air quality based on the concentration and duration of pollutant exposure.[17] Indeed, the scientific literature indicates that reduced exposure to air pollution may bring about several beneficial biological mechanisms. Enhanced pulmonary function, increased hemoglobin levels, and improved cardiovascular health can contribute to more efficient oxygen transport and utilisation.[29] Moreover, reductions in inflammation and oxidative stress have been shown to promote greater muscular efficiency, among other positive physiological adaptations.[30] Overall, improvements in air quality can have a significant positive impact on both athletic performance and public health by supporting the physiological processes associated with increases in $\dot{V}O_2max$. These enhancements are closely linked to athletic training and performance improvements. The current study acknowledges several limitations, particularly regarding the control of training regimens across both groups. For a comprehensive analysis of the factors influencing the observed changes, it is essential to meticulously document and quantify the training processes and loads throughout the study period, utilizing these data as a moderating variable. This oversight introduces a potential bias, suggesting that the generalizability of the findings should be approached with caution. Future research should prioritize the monitoring of training loads and consider these as co-variables to enhance the robustness of the results. Despite these limitations, both groups were matched in terms of competition category, age, stature, body mass, and BMI, which helps mitigate confounding variables. It is reasonable to assume that the training processes for these categories were relatively uniform, with no significant disparities in overall training loads or methodologies. However, the study did not account for the duration of exposure to specific training objectives, which could have led to differential impacts on cardiorespiratory fitness between the groups.

Future investigations could benefit from observational studies that assess decision-making actions and typical player behaviors, such as the execution of vertical and horizontal passes, contextualized by varying air quality conditions. Additionally, monitoring fluctuations in physical conditioning throughout the season, comparing periods of good air quality with those of poor air quality, may provide valuable insights. This research represents one of the first studies in Spain to investigate the impact of air quality on young soccer players, thereby contributing to the broader understanding of how environmental factors affect athletic performance. Such investigations are essential for optimizing physical and physiological performance during training, particularly from a sports medicine perspective.

Practical recommendations for coaches and health professionals could include designing training schedules that prioritize high-intensity sessions during periods of favorable air quality and routinely monitoring pollution levels. Coaches should be encouraged to educate players about the signs of diminished performance related to poor air quality and to adjust training programs accordingly. Furthermore, health professionals could promote the use of air quality monitoring tools to support informed decision-making regarding appropriate training environments.

Conclusions

The present study demonstrated that young soccer players exposed to elevated levels of particulate pollution experienced significant reductions in their maximal oxygen uptake during the pre-test compared to their counterparts in cleaner environments. However, there was a notable increase in maximal oxygen uptake in the post-test, indicating that high particulate pollution may exert both immediate (pre-test) and chronic effects due to prolonged exposure over time. To mitigate these adverse health impacts, it is advisable for young players in the experimental group to train indoors during periods of high pollution. Additionally, installing air quality monitoring systems in the village would facilitate the development of proactive schedules and plans to safeguard the health of these athletes. In conclusion, it can be inferred that young soccer players in Villanueva del Arzobispo (Spain) may experience detrimental effects on their maximal oxygen uptake due to the unfavorable conditions associated with high particulate pollution, especially when compared to populations in areas with better air quality.

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Authors' contributions

Conceptualization, F.T.G.F. and F.M.C., methodology, F.T.G.F. and L.M.M-A., data collection, F.T.G.F. analysis, F.T.G.F. and L.M.M-A., writing—original draft preparation, A.C.R., F.M.C., and L.M.M-A., writing—review and editing, F.M.C., J.C.C.M., G.B and L.M.M-A. All authors have read and agreed to the published version of the manuscript.

Data availability statement

The datasets generated and analyzed during the current study are available from F.T.G. F on reasonable request. Only V02max and category of the athletes may be shared without identification of the participants.

Declaration of conflicting interests

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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Institutional review board statement

The study was conducted according to the guidelines of the Declaration of Helsinki and approved by the Research Ethics Committee of the University of Comillas (code: 2021/89).

Informed consent statement

The participants' parents were informed about the objectives of the investigation and signed consent forms detailing their possible benefits and risks. Families were informed that they could revoke the participation agreement at any time. All participants were verbally informed and asked to provide consent prior to the intervention. The participants were fully debriefed about the purpose of the study at the end of the experiments. Every family was verbally informed and asked to provide consent prior to the completion of each test and intervention.

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