Submission ID: 20133

Please find attached Written Representation regarding Luton Town Football Club's training and new stadium.

Written Evidence - Luton Town Football Club Training Ground - Deadline 1

Stop Luton Airport Expansion (SLAE) would like to suggest a visit to Luton Town Football Clubs training ground at the Brache, Gypsy Lane, Luton. We don't think that this has been a site visit yet. The visit might need to be accompanied and with permission from the football club. We are happy to contact the club to ask for permission.

We have not found anywhere in the applicant documents any consideration of the impact of their expansion proposals on the football club or their athletes. Can LR provide document references?

We are concerned that the Luton Town Football Club training ground is under the flight path and that the athletes will be exposed to increased pollution, noise and other impacts of aviation and aircraft taking off from and landing at the airport. Why is the not covered in the application?

The football club are also planning to relocate from their present ground in Kenilworth Road to a planned new stadium in Power Court, which is on the airport side of the town centre and at the bottom of the valley. They and visiting teams will be prone to aircraft and aviation pollution there as well. SLAE could not find references to pollution from the airport at Power Court?

With a consultation costing up to £65 million, we are surprised that after 5 years of airport planning for the consultation that this item has not been picked up at all by Luton Borough Council or Luton Rising.

Do LR and LBC not have the competent experts with the expertise to understand this subject and the health of professional elite athletes when performing at their maximum? Tiny margins matter when top athletes compete and aviation pollution may just make the difference between winning or losing.

They can be forgiven as this is a very specialised subject and we are not aware of any UK organisation researching into this.

Evidence taken from researchers and available on the internet.

Evidence WR LTFC c

- Air Pollutants Reduce the Physical Activity of Professional Soccer Players
https://www.ncbi.nlm.nih.gov/pmc/articles/PMC8701275/ (accessed 20/8/23)

Evidence WR LTFC d

- Can Professional Football Players Adapt to Air Pollution? Evidence From China
https://journals.sagepub.com/doi/abs/10.1177/15270025211049793?journalCode=jsea (accessed 20/8/23)

Evidence WR LTFC e

- Exercise and outdoor ambient air pollution
https://bjsm.bmj.com/content/35/4/214 (accessed 20/8/23)

Evidence WR LTFC f

- https://www.theguardian.com/environment/2016/mar/05/air-pollution-football-performance (accessed 20/8/23)

We have also not seen any football crowd / traffic modelling in the expansion consultation documents for when the new stadium is built, which will also use the same road network as airport traffic. Please provide where in the application this information can be found? Document 000966, drawings LLADCO-3C-ARP-SFA-HWM-DR-CE-0002, LLADCO-3C-ARP-SFA-HWM-DR-CE-0003, LLADCO-3C-ARP-SFA-HWM-DR-CE-0004, LLADCO-3C-ARP-SFA-HWM-DR-CE-0005, LLADCO-3C-ARP-SFA-HWM-DR-CE-0006, LLADCO-3C-ARP-SFA-HWM-DR-CE-0015.

The new stadium at Power Court is due to hold a crowd of 19,500 initially and expanding to 23,000. Outline planning permission was given in 2019. This will generate additional traffic.

https://www.bbc.co.uk/news/uk-england-beds-bucks-herts-65718990 (accessed 20/8/23).

Evidence WR LTFC a


The Linden Academy
Primary School
River Lea
ALDI
Gipsy Ln
Alton Rd
Park St
Venue 360 -
The Riverside
Lifelines Health
Club & Gym
Luton Town FC
Training Ground
HOYLAKE COURT
Venu
Park St
Park St
New Airport Wy
A1081
A1081
New Airport Wy
Google

Evidence WR LTFC b


Luton Airport Parkway
River Lea
Venue 360 -
The Riverside
Car Park Luto
Parkway Stat
Google

Evidence WR LTFC c

- **Air Pollutants Reduce the Physical Activity of Professional Soccer Players**
  https://www.ncbi.nlm.nih.gov/pmc/articles/PMC8701275/ (accessed 20/08/23)

Journal List Int J Environ Res Public Health PMC8701275

Int J Environ Res Public Health. 2021 Dec; 18(24): 12928.

Published online 2021 Dec 8. doi: 10.3390/ijerph182412928

PMCID: PMC8701275

PMID: 34948538

Air Pollutants Reduce the Physical Activity of Professional Soccer Players

Michał Zacharko,1,* Robert Cichowicz,2 Marcin Andrzejewski,3 Paweł Chmura,1 Edward Kowalczuk,4 Jan Chmura,1 and Marek Konefał1

Yu-Hsiang Cheng, Academic Editor, Elisabete Carolino, Academic Editor, and Chi-Chi Lin, Academic Editor

Author information Article notes Copyright and License information PMC Disclaimer

Associated Data

Data Availability Statement

Go to:

Abstract

The aim of the study was to determine the impact of air quality—analyzed on the basis of the model of integrating three types of air pollutants (ozone, O3; particulate matter, PM; nitrogen dioxide, NO2)—on the physical activity of soccer players. Study material consisted of 8927 individual match observations of 461 players competing in the German Bundesliga during the 2017/2018 and 2018/2019 domestic seasons. The measured indices included players' physical activities: total distance (TD) and high-intensity effort (HIE). Statistical analysis showed that with increasing levels of air pollution, both TD ($F = 13.900(3)$; $p = 0.001$) and HIE ($F = 8.060(3)$; $p = 0.001$) decrease significantly. The worsening of just one parameter of air pollution results in a significant reduction in performance. This is important information as air pollution is currently a considerable problem for many countries. Improving air quality during training sessions and sports competitions will result in better well-being and sporting performance of athletes and will also help protect athletes from negative health effects caused by air pollution.

Keywords: football, Bundesliga, distances covered, high intensity, O3, PM, NO2, air quality

Go to:

1. Introduction

As Reche et al. [1] and Fitch [2] indicate inhalation of high concentrations of air pollutants can cause more harm to athletes who undertake intensive training than to the general public. Athletes are especially vulnerable, as their air intake is higher, and many train and compete outdoors for large portions of the day [1]. During intense exercise, athletes can breathe more than 6000 L/h compared with perhaps 4–500 L/h at rest and 1000 L/h with light exercise [2]. It is caused, among other things, by increased lung ventilation during exercise [3]. Inhaling more air through the mouth during exercise causes a bypassing of the nasal filtration mechanisms. Increased air flow velocity transports pollutants deep into the respiratory tract and thus increases the uptake of gaseous pollutants [4], and thus, the concentration levels of individual pollutants in the human body also increase. Despite the studies cited above, there is a scarcity of research on the physical activity of professional athletes in a potentially polluted environment [5] and in particular on soccer players [6].

It is worth noting that the number and frequency of professional football matches played is high. Modern competitive schedules are very demanding, with teams having to play up to 60 matches per season [7]. Each match requires players to be very physically active, which is defined, among other things, by total distance covered (TD) and high-intensity effort (HIE). The average TD in a Bundesliga match ranges from 10.03 ± 0.61 to 11.55 ± 0.70 km, and the number of HIE from 30.33 ± 7.64 to 47.48 ± 12.30 depending on the position on the field [8]. The above parameters are very important because they significantly correlate with match outcome. For example, Andrzejewski et al. [9] found that winning a match correlates with the players of the winning team covering a greater total distance. Elsewhere, both Modric et al. [10] and Chmura et al. [11] are of the view that high-intensity efforts (fast running and sprinting) are some of the most important measures of physical efficiency in football.

As a result of extensive physical activities that soccer players undertake during a match, there is a high probability of physiological changes, one of which may be the appearance of oxidative stress in the respiratory tract. This is the major pathophysiological factor in adverse vascular health effects of air pollution. The presence of oxidative stress in the lungs has also been documented and almost certainly occurs with immediate exposure [12]. Furthermore, oxidative stress increases lipid peroxidation, generation of secondary mediators that enhance oxidative stress-induced damage, and a reduction in levels of the primary lung antioxidant, glutathione [13]. Depletion of low molecular weight antioxidants, such as glutathione, ascorbate, and tocopherol, along with subsequent reductions of cofactors, such as NADPH, may increase the risk and impact of oxidative stress [14]. It should also be highlighted that in previous research markers of airway inflammation [15] and oxidative stress [16,17] have been detected after exposure to PM and to O3. Indeed, PM exposure can directly lead to the expression of particles that cause airway wall fibrosis and play a major role in airway obstruction.

The problem of air quality has been noted by the World Health Organization (WHO), which estimated that, in 2012, about 7 million deaths were associated with living in the areas with polluted air. This is a global problem that affects many countries around the world [18,19,20]. Elevated and/or exceeded levels of air pollutants in certain periods and locations also apply to European countries considered highly developed in terms of their economy and industry. In Germany most urban areas still do not meet WHO air quality standards [21]. Although there are various air quality assessment scales, the domestic ones are usually less strict than European standards. Even so, air quality standards or guidelines are often not met. Among the most frequently analyzed and controlled pollutants are: ozone (O3), particulate matter (PM), and nitrogen dioxide (NO2). The first of these, ozone, is a gas produced by the action of sunlight on hydrocarbons and nitrogen oxides [22] and is detrimental to athletic performance when exposure is high enough. Subsequent respiratory discomfort associated with increased exposure to ozone may cause a reduction in maximum work efficiency and significantly contribute to an increase in the overall perceived exertion [23]. Particulate matter is produced mainly from the combustion of fuels in gasoline and diesel engines, the combustion of wood and fossil fuels, and during construction works [24]. There are different criteria for the division of particulates; however, the most frequently analyzed are particulates such as PM10 (with particle diameter below 10 μm), PM2.5 (below 2.5 μm), and PM1 (below 1 μm) [2]. The smaller the particle, the greater its potential to cause harm because it can penetrate more deeply into the lungs. However, even PM10 has a detrimental effect on health, as its combination with sulfur dioxide (SO2) and water vapor creates sulfuric acid-coated particles that can settle in the lungs and cause irritation and asthma-like symptoms [22]. Nitrogen dioxide, on the other hand, is a by-product of the combustion of fossil fuels [22]. NO2 tends to coexist with PM and usually O3, and they are often inhaled simultaneously [2]. As a result, they have a comprehensive effect on the human body, and for this reason, it seems important to analyze all three of the above types of pollutants simultaneously, especially given the fact that the literature lacks studies that show the integrated effect of the three most often described parameters of air pollution on the body of professional athletes.

Numerous studies show a relationship between air pollution and the cardiovascular and respiratory systems [13,25], and adverse changes in biomarkers of physiological and biochemical functions have also been identified [26]. This is directly related to the performance of the athlete’s body and thus to their activity during sports competitions. In order to address this problem and consider the above-mentioned information, it was decided that the aim of the study would be to determine the impact of air quality analyzed on the basis of the model of integrating three types of air pollutants (O3, NO2, PM10) on the physical activity of football players in the Bundesliga. We hypothesize that as the levels of air pollution increase, players’ physical activity worsens.

Go to:

2. Materials and Methods

2.1. Match Sample and Data Collection

Match performance data were collected from 461 soccer players competing in the German Bundesliga during the 2017/2018 and 2018/2019 domestic seasons. In every season, the league's 18 teams face each opponent twice per season, home and away. Thus, a season comprises of 34 match days and 306 matches, typically held on weekends between August and May [6]. A total of 8927 individual match observations were made of outfield players (goalkeepers were excluded). Only data for players completing entire matches (i.e., on the pitch for the whole 90 min) were considered.

Data were obtained using the IMPIRE AG system with a recording frequency of 25 Hz [27]. Each player's movements were recorded by two cameras [28]. The system utilizes state-of-the-art algorithms and 2-D and 3-D video-recording technology, allowing for detailed motion analysis of entire soccer matches. The major advantages of vision-based systems are their high update rate corresponding to the camera-frame rate and the fact that the players and the ball are tracked simultaneously. The validity and reliability of this system have been described in detail elsewhere [28]. Furthermore, Liu et al. [29] showed that team match events coded by independent operators using this system achieved very good levels of agreement (weighted kappa values of 0.92 and 0.94), with the average difference of event time equal to 0.06 ± 0.04 s.

This study maintains the anonymity of the players following data protection laws, is conducted in compliance with the Declaration of Helsinki, and was approved by the Senate Committee on Ethics of Scientific Research at the Academy of Physical Education in Wroclaw (No. 12/2021).

2.2. Procedures

Air quality data was determined on the basis of records from the air pollution monitoring system of the German Environment Agency [30]. This is Germany's main environmental protection agency and is also a German point of contact for numerous international organizations, such as the WHO. The following air pollution parameters were analyzed: particulate matter smaller than ten micrometers (PM10), nitrogen dioxide (NO2), and ozone (O3) [31]. The data were read from air pollution meters closest to the stadiums where the matches were played (average distance 3.5 km). For each analyzed match, the mean value of air pollution readings was determined from the data recorded at the beginning and end of the match (average over two hours). In the following stage, the average value of the readings for each parameter was classified as very good, good, moderate, sufficient, bad, or very bad, in accordance with the standards adopted in Poland by the Main Inspectorate Of Environmental Protection [32]—Table 1. The above scale makes it possible to accurately assess all tested parameters and is also widely used in scientific research [24,33].

Table 1

Inspectorate of Environmental Protection (Poland) norms for hourly concentrations and assigned point values.

Air Quality Index	Air Pollution Parameter			
	PM10 (μg/m3)	O3 (μg/m3)	NO2 (μg/m3)	Points
Very good	0–20	0–70	0–40	1
Good	20.1–50	70.1–120	40.1–100	2
Moderate	50.1–80	120.1–150	100.1–150	3
Sufficient	80.1–110	150.1–180	150.1–200	4
Bad	110.1–150	180.1–240	200.1–400	5
Very bad	>150	>240	>400	6

Open in a separate window

For each “air quality index”, point values were assigned from 1 (very good) to 6 (very bad)—Table 1. Then, based on the sum of point values assigned to individual “air quality index” categories, a model of integrating three types of air pollutants was created. Based on this model, 4 air quality categories were created: “very good”—the sum of the point values for the three tested parameters (PM10, O3, NO2) is 3; “fair”—the sum of the point values for the three tested parameters is 4; “moderate”—the sum of the score values for the three parameters tested is 5; and “poor”—the sum of the point values for the three tested parameters is at least 6.

In the model of integrating selected air pollution parameters, “very good” (2563 observations) means that all three parameters subject to observation had a “very good air quality index” (e.g., 1 + 1 + 1 = 3). For “fair” (3749 observations), one of the parameters had a higher point value, defined in the “air quality index” as “good” (e.g., 2 + 1 + 1 = 4). For “moderate” (1882 observations), for example, one of the parameters had a point value of 1, and the other two parameters had a point value of 2 (e.g., 1 + 2 + 2 = 5). For “poor” (733 observations), many configurations are possible (e.g., 3 + 2 + 1 = 6).

The measured indices included players’ physical activities: total distance (TD, distance covered by a player during match play) and high-intensity effort (HIE, running efforts (velocity > 4 m/s) achieved by a player during match play). Complete definitions of physical variables are available at the Deutsche Fußball Liga (DFL) [34]. Definitionskatalog Offizielle Spieldaten—Bundesliga website https://s.bundesliga.com/assets/doc/10000/2189_original.pdf (accessed on 20/8/23).

2.3. Statistical Analyses

All variables were checked to verify their conformity with a normal distribution. Arithmetic means and standard error were calculated. Spearman's correlations were used. Then repeated-measures ANOVA was used to compare mean values for the examined variables. Fisher LSD (Least Significant Difference) post-hoc tests were performed to assess differences between means. Moreover, partial eta squared (η2) was calculated [35]. All statistical analyses were performed using the Statistica ver. 13.1 software package (Dell Inc., Tulsa, OK, USA).

Go to:

3. Results

The following mean levels and standard errors of air pollution parameters were recorded during the study: PM10, 19.04 ± 0.12 (confidence interval −95%—18.80; confidence interval 95%—19.28) (µg/m3); O3, −56.50 ± 0.32 (confidence interval −95%—55.87; confidence interval 95%—57.13) (µg/m3); NO2, −36.07 ± 0.37 (confidence interval −95%—35.34; confidence interval 95%—36.79) (µg/m3). Value of air pollution parameters for individual air quality categories are shown in Table 2.

Table 2

Value of air pollution parameters for individual air quality categories (mean ± SE).

Air Quality Index	Air Pollution Parameter			
	PM10 (µg/m3)	O3 (µg/m3)	NO2 (µg/m3)	Points
Very good	12.51 ± 0.06	40.47 ± 0.25	19.56 ± 0.14	1
Good	29.28 ± 0.14	86.73 ± 0.26	57.80 ± 0.25	2
Moderate	59.92 ± 0.43	132.47 ± 0.57	116.72 ± 1.13	3
Sufficient	-	-	-	4
Bad	-	-	272.58 ± 4.33	5
Very bad	-	-	-	6

Open in a separate window

We did not find any correlations between the individual air pollution parameters (PM10, O3, NO2) and players' physical activities (TD, HIE): PM10 and TD rs = −0.045; PM10 and HIE rs = −0.013; O3 and TD rs = −0.108; O3 and HIE rs = −0.093; NO2 and TD rs = 0.005; and NO2 and HIE rs = 0.040. Then, a model was developed that integrated the three types of air pollutants was created.

The statistical analysis of player's physical activities as set against air quality categories (very good, fair, moderate, poor) revealed effects in relation to the TD ($F = 13.900(3)$; $p = 0.001$; $\eta 2 = 0.005$), as shown in Figure 1, and HIE ($F = 8.060(3)$; $p = 0.001$; $\eta 2 = 0.003$), as shown in Figure 2.

An external file that holds a picture, illustration, etc.

Object name is ijerph-18-12928-g001.jpg

Figure 1

Differences in total distance covered by soccer players in relation to changes in air quality categories (mean ± SE). Differences statistically significant between very good vs. fair $p = 0.01$, fair vs. moderate $p = 0.01$, and moderate vs. poor $p = 0.05$ (Source: own elaboration).

An external file that holds a picture, illustration, etc.

Object name is ijerph-18-12928-g002.jpg

Figure 2

Differences in high-intensity effort of soccer players in relation to changes in air quality categories (mean ± SE). Differences statistically significant between very good vs. fair $p = 0.01$ and fair vs. moderate $p = 0.05$ (Source: own elaboration).

Go to:

4. Discussion

The study aimed to determine the impact of air quality—analyzed on the basis of the model of integrating three types of air pollutants ($O3$, $NO2$, PM10)—on the physical activity of soccer players in the Bundesliga. So far, little research has been undertaken in this field in relation to athletes. Rundell [5] analyzed ice hockey players and skaters and identified that PM products from diesel-powered Zambonis (ice resurfacing machines used in ice rinks) was a factor in the increased prevalence of asthma and airway hyperresponsiveness. His research identified that even warming-up while breathing polluted air containing PM could reduce exercise performance. Whilst that study concerned indoor sport, studies on outdoor sports, where the analysed material is derived from mostly runners or cyclists, are more popular. For example, El Helou et al. [36] found that higher ozone levels were associated with poorer performance in six city marathons. Reduced lung function has also been observed among runners after they ran near busy highways [17] and among cyclists after they rode along heavy traffic routes during rush-hour traffic [37].

Our study is both original and important because, thus far, to the best of our knowledge, only one study on the effects of air quality on the activity of professional soccer players has been published. This is surprising because soccer is one of the most popular outdoor sports; according to the latest FIFA Professional Football Report, it is played by over 128,000 professional football players from 187 countries [38]. In the study concerned, Lichter et al. [6] assessed the effects of particulate air pollution on soccer players in German stadiums, revealing that performance was reduced under poor air quality conditions. In that study, PM10 was the only factor taken into account, and the productivity indicator was limited to only the number of passes during a match. However, total distance covered and high intensity effort seem to be more valuable parameters for assessing performance in the context of air quality because soccer is considered a high-intensity, intermittent sport with an unprecedented increase (up to 50%) in high-impulsive actions occurring during match play [39]. Moreover, high-intensity running and accelerations are nowadays the most crucial activities where elite soccer-match performance is concerned [40]. Therefore, in our analysis, the range of measured parameters of air pollutants was significantly expanded, and it was decided that physical activities be included too. Thanks to this, we were able to discover that lowering the air quality level during the match not only negatively affects technical activities, such as passes [6], but also the most important physical activities, such as TD and HIE. Our analysis shows that each level of air quality deterioration significantly reduces both the TD covered by the players and the number of HIE. The difference between the average distance travelled by each player in matches with “very good air quality” and “poor air quality” is 0.2 km (approximately 2 km for the entire team), and the difference in the number of HIEs performed is two repetitions, i.e., as much as 20 for the entire team, which may indirectly impact the game result [11].

In our study, in conditions of “poor air quality” footballers covered the distance 10.84 ± 0.90 km and performed 41.57 ± 12.12 number of HIE. Duda et al. [41] claimed that during enhanced physical activity, athletes inhale up to 20 times more air than during a walk, and a great amount of toxic substances enter their bodies and poison the body’s tissue. The greater amount of particulate matter and nitrogen dioxide that enter the body with polluted air may increase bronchiolar fibrosis and play a major role in airway obstruction [42,43]. Exposure to ozone, on the other hand, impairs the function of the endothelium of the ductal vessels [44]. This can result in, amongst other things, endogenous airway acidification episodes indicative of pollution-related lung inflammation [45]. Furthermore, a study by Kargarfard et al. [25] showed that a high concentration of pollutants during physical activities slows cardiovascular functions as well as impacting hematological parameters. Thus, air quality during a football match is extremely important because, together with increased physical effort, the body absorbs harmful substances from the air [46]. Each of the selected air pollutants included in our study (PM10, O3, NO2) causes other negative effects in the human body. However, all three of them are particularly dangerous, which is confirmed by the research by Rundell et al. [13] and Tainio et al. [31].

In view of the harmful effects of air pollution on the human body, it is worth considering what should be done to improve air quality at stadiums and how not to expose athletes and fans to negative health effects. One possible way in which better natural environments might aid health and athletic performance is through mitigation of risk from environmental pollutants. Existing research on this topic has shown that trees can reduce the level of air pollutants in urban areas [47], with one study claiming that in the U.S., trees remove 711,000 tons of air pollutants per year [48]. With regard to athletes, De Wolfe et al. [49] looked into the performance of 128 college-level track and field competitors across four locations that differed in their greenness. The authors found that greenness was a predictor of performance ($r2 = 0.61$, $p < 0.001$), with athletes' best performances being more likely to occur at the most "green" site. Therefore, it is worth paying attention to having as much greenery as possible in the vicinity of football stadiums. At sites where substantial tree planting in surrounding areas is not possible, roof spaces can be used to green the area. Yang et al. [50] estimated that 1675 kg of air pollutants were removed by 19.8 hectares of green roofs in one year in Chicago. Another way is to install various types of air purification filters near stadiums, which are able to reduce the concentration of particulates in the air by up to about 2 million milligrams per month [51]. By applying the above solution, air pollution during matches will likely be reduced, and both footballers and fans will be less exposed to the negative health effects caused by poor air quality.

The authors are fully aware of the many factors that might have influenced the results of the analyses presented here [52]. The monitoring location was determined at the measuring stations closest to the stadiums. However, to make the measurements more precise, in subsequent analyses, we suggest placing air pollution meters directly next to the stadiums. In addition, the meteorological conditions and the type of buildings between the measuring station and the stadium were not taken into account, and this may have an impact on the actual air quality in a particular stadium. A further limitation concerns the failure to take account of many other parameters helping to characterize external load, such as player load, sprints, acceleration, deceleration, impact of age, and positions, which all also serve to express the demands imposed by matches in non-cyclic team sports. It should also be noted that the linear associations with the individual pollutants (PM10, O3, NO2) were not significant. This may be due to the above-mentioned limitations, and therefore, more research is needed to properly assess the individual pollutant values.

Go to:

5. Conclusions

An important new finding of the present study is that air quality significantly impacts the physical activity of soccer players. As air pollution levels increase, physical activity during a match decreases. Worsening of just one parameter of air pollution is enough to result in a significant reduction in performance, and this may be a consequence of negative physiological reactions in the body. This is an important finding because air pollutants are currently a significant problem in many countries, and our study is further evidence that action should be taken to improve air quality. Improving air quality during training and sports competitions will result in better well-being and sporting performance of athletes and will also help protect athletes from the negative health effects caused by air pollution.

Go to:

Author Contributions

Conceptualization, M.Z., R.C. and M.K.; data curation, M.Z., R.C., E.K. and M.K.; formal analysis, M.Z., R.C., M.A., P.C. and M.K.; funding acquisition, M.Z., J.C. and M.K.; investigation, M.Z., R.C., M.A., P.C. and M.K.; methodology, M.Z., R.C., M.A., P.C. and M.K.; project administration, M.Z., M.A., P.C., J.C. and M.K.; resources, M.Z., R.C., M.A., P.C. and M.K.; software, M.Z., E.K. and M.K.; supervision, M.Z., R.C., M.A., P.C., J.C. and M.K.; validation, M.Z., R.C., J.C. and M.K.; visualization, M.Z., R.C., M.A., P.C. and M.K.; writing—original draft, M.Z. and M.K.; writing—review and editing, M.Z., R.C., M.A., P.C., J.C. and M.K. All authors have read and agreed to the published version of the manuscript.

Go to:

Funding

This research received no external funding.

Go to:

Institutional Review Board Statement

The study was conducted according to the guidelines of the Declaration of Helsinki, and approved by the Senate Committee on Ethics of Scientific Research at the Academy of Physical Education in Wroclaw (No. 12/2021).

Go to:

Informed Consent Statement

Not applicable.

Go to:

Data Availability Statement

The data used in this research were acquired from a third party: https://matchanalysishub.bundesliga.com/login (accessed on 20/8/23). The data were provided as part of a scientific cooperation agreement with a professional football club that plays in the 2. Bundesliga. In line with ethical approval for the research, the authors are also prevented from sharing any data that could be re-identified, as a combination of the metadata and the score data would allow for teams, and possibly also players, to be re-identified. However, access to these data is possible from the third-party. The data acquired for this investigation were so-called "excel dumps" of player statistics for each match during the 2017–18 and 2018–19 seasons. Access to the data can be sought via Match Analysis Hub: e[redacted]@cdm.

Go to:

Conflicts of Interest

The authors declare no conflict of interest.

Go to:

Footnotes

Publisher's Note: MDPI stays neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Go to:

References

1. Reche C., Viana M., van Drooge B.L., Fernández F.J., Escribano M., Castaño-Vinyals G., Nieuwenhuijsen M., Adami P.E., Bermon S. Athletes' exposure to air pollution during World Athletics Relays: A pilot study. Sci. Total Environ. 2020;717:137161. doi: 10.1016/j.scitotenv.2020.137161. [PubMed] [CrossRef] [Google Scholar]

2. Fitch K. Air pollution, athletic health and performance and the Olympic Games. J. Sports Med. Phys. Fit. 2015;56:922–932. [PubMed] [Google Scholar]

3. Flaherty J.M., Smoliga J.M., Zavorsky G.S. The effect of increased physical activity on pulmonary diffusing capacity in unfit women. Exp. Physiol. 2014;99:562–570. doi: 10.1113/expphysiol.2013.076406. [PubMed] [CrossRef] [Google Scholar]

4. Lü J., Liang L., Feng Y., Li R., Liu Y. Air Pollution Exposure and Physical Activity in China: Current Knowledge, Public Health Implications, and Future Research Needs. Int. J. Environ. Res. Public Health. 2015;12:14887–14897. doi: 10.3390/ijerph121114887. [PMC free article] [PubMed] [CrossRef] [Google Scholar]

5. Rundell K.W. Effect of air pollution on athlete health and performance. Br. J. Sports Med. 2012;46:407–412. doi: 10.1136/bjsports-2011-090823. [PubMed] [CrossRef] [Google Scholar]

6. Lichter A., Pestel N., Sommer E. Productivity effects of air pollution: Evidence from professional soccer. Labour Econ. 2017;48:54–66. doi: 10.1016/j.labeco.2017.06.002. [CrossRef] [Google Scholar]

7. Carling C., Lacome M., McCall A., Dupont G., Le Gall F., Simpson B., Buchheit M. Monitoring of Post-match Fatigue in Professional Soccer: Welcome to the Real World. Sports Med. 2018;48:2695–2702. doi: 10.1007/s40279-018-0935-z. [PMC free article] [PubMed] [CrossRef] [Google Scholar]

8. Konefał M., Chmura P., Tessitore A., Melcer T., Kowalczuk E., Chmura J., Andrzejewski M. The Impact of Match Location and Players' Physical and Technical Activities on Winning in the German Bundesliga. Front. Psychol. 2020;11:1748. doi: 10.3389/fpsyg.2020.01748. [PMC free article] [PubMed] [CrossRef] [Google Scholar]

9. Andrzejewski M., Chmura P., Konefał M., Kowalczuk E., Chmura J. Match outcome and sprinting activities in match play by elite German soccer players. J. Sports Med. Phys. Fit. 2018;58:785–792. doi: 10.23736/S0022-4707.17.07352-2. [PubMed] [CrossRef] [Google Scholar]

10. Modric T., Versic S., Sekulic D., Liposek S. Analysis of the Association between Running Performance and Game Performance Indicators in Professional Soccer Players. Int. J. Environ. Res. Public Heath. 2019;16:4032. doi: 10.3390/ijerph16204032. [PMC free article] [PubMed] [CrossRef] [Google Scholar]

11. Chmura P., Konefał M., Chmura J., Kowalczuk E., Zając T., Rokita A., Andrzejewski M. Match outcome and running performance in different intensity ranges among elite soccer players. Biol. Sport. 2018;35:197–203. doi: 10.5114/biolsport.2018.74196. [PMC free article] [PubMed] [CrossRef] [Google Scholar]

12. Rao X., Zhong J., Brook R.D., Rajagopalan S. Effect of Particulate Matter Air Pollution on Cardiovascular Oxidative Stress Pathways. Antioxid. Redox Signal. 2018;28:797–818. doi: 10.1089/ars.2017.7394. [PMC free article] [PubMed] [CrossRef] [Google Scholar]

13. Rundell K.W., Anderson S.D., Sue-Chu M., Bougault V., Boulet L. Air Quality and Temperature Effects on Exercise-Induced Bronchoconstriction. Compr. Physiol. 2015;5:579–610. doi: 10.1002/cphy.c130013. [PubMed] [CrossRef] [Google Scholar]

14. Pöschl U., Shiraiwa M. Multiphase Chemistry at the Atmosphere–Biosphere Interface Influencing Climate and Public Health in the Anthropocene. Chem. Rev. 2015;115:4440–4475. doi: 10.1021/cr500487s. [PubMed] [CrossRef] [Google Scholar]

15. Barraza-Villarreal A., Sunyer J., Cadena L.H., Escamilla-Nuñez M.C., Sienra-Monge J.J., Ramírez-Aguilar M., Cortez-Lugo M., Holguin F., Diaz-Sanchez D., Olin A.C., et al. Air Pollution, Airway Inflammation, and Lung Function in a Cohort Study of Mexico City Schoolchildren. Environ. Health Perspect. 2008;116:832–838. doi: 10.1289/ehp.10926. [PMC free article] [PubMed] [CrossRef] [Google Scholar]

16. Campen M.J., Lund A., Rosenfeld M. Mechanisms linking traffic-related air pollution and atherosclerosis. Curr. Opin. Pulm. Med. 2012;18:155–160. doi: 10.1097/MCP.0b013e32834f210a. [PMC free article] [PubMed] [CrossRef] [Google Scholar]

17. Rundell K.W., Slee J.B., Caviston R., Hollenbach A.M. Decreased Lung Function After Inhalation of Ultrafine and Fine Particulate Matter During Exercise is Related to Decreased Total Nitrate in Exhaled

Breath Condensate. Inhal. Toxicol. 2008;20:1–9. doi: 10.1080/08958370701758593. [PubMed] [CrossRef] [Google Scholar]

18. Khilnani G.C., Tiwari P. Air pollution in India and related adverse respiratory health effects: Past, present, and future directions. Curr. Opin. Pulm. Med. 2018;24:108–116. doi: 10.1097/MCP.0000000000000463. [PubMed] [CrossRef] [Google Scholar]

19. Tian L., Sun S. Comparison of Health Impact of Air Pollution between China and Other Countries. Adv. Exp. Med. Biol. 2017;1017:215–232. doi: 10.1007/978-981-10-5657-4_9. [PubMed] [CrossRef] [Google Scholar]

20. Cichowicz R., Wielgosiński G., Fetter W. Dispersion of atmospheric air pollution in summer and winter season. Environ. Monit. Assess. 2017;189:605. doi: 10.1007/s10661-017-6319-2. [PMC free article] [PubMed] [CrossRef] [Google Scholar]

21. Petrowski K., Bastianon C.D., Bührer S., Brähler E. Air Quality and Chronic Stress: A Representative Study of Air Pollution (PM2.5, PM10) in Germany. J. Occup. Environ. Med. 2019;61:144–147. doi: 10.1097/JOM.0000000000001502. [PubMed] [CrossRef] [Google Scholar]

22. Lippi G., Guidi G., Maffulli N. Air Pollution and Sports Performance in Beijing. Int. J. Sports Med. 2008;29:696–698. doi: 10.1055/s-2008-1038684. [PubMed] [CrossRef] [Google Scholar]

23. Carlisle A.J., Sharp N.C. Exercise and outdoor ambient air pollution. Br. J. Sports Med. 2001;35:214–222. doi: 10.1136/bjsm.35.4.214. [PMC free article] [PubMed] [CrossRef] [Google Scholar]

24. Cichowicz R., Stelegowski A. Average Hourly Concentrations of Air Contaminants in Selected Urban, Town, and Rural Sites. Arch. Environ. Contam. Toxicol. 2019;77:197–213. doi: 10.1007/s00244-019-00627-8. [PMC free article] [PubMed] [CrossRef] [Google Scholar]

25. Kargarfard M., Shariat A., Shaw B.S., Shaw I., Lam E.T.C., Kheiri A., Eatemadyboroujeni A., Tamrin S.B.M., Shhariat A. Effects of Polluted Air on Cardiovascular and Hematological Parameters After Progressive Maximal Aerobic Exercise. Lung. 2015;193:275–281. doi: 10.1007/s00408-014-9679-1. [PubMed] [CrossRef] [Google Scholar]

26. Brook R.D., Rajagopalan S., Pope C.A., Brook J.R., Bhatnagar A., Diez-Roux A.V., Holguin F., Hong Y., Luepker R.V., Mittleman M.A., et al. Particulate matter air pollution and cardiovascular disease: An update to the scientific statement from the American Heart Association. Circulation. 2010;121:2331–2378. doi: 10.1161/CIR.0b013e3181dbece1. [PubMed] [CrossRef] [Google Scholar]

27. Tiedemann T., Francksen T., Latacz-Lohmann U. Assessing the performance of German Bundesliga football players: A non-parametric metafrontier approach. Cent. Eur. J. Oper. Res. 2010;19:571–587. doi: 10.1007/s10100-010-0146-7. [CrossRef] [Google Scholar]

28. Link D., Weber H. Effect of Ambient Temperature on Pacing in Soccer Depends on Skill Level. J. Strength Cond. Res. 2017;31:1766–1770. doi: 10.1519/JSC.0000000000001013. [PubMed] [CrossRef] [Google Scholar]

29. Liu H., Hopkins W., Gómez A.M., Molinuevo S.J. Inter-operator reliability of live football match statistics from OPTA Sportsdata. Int. J. Perform. Anal. Sport. 2013;13:803–821. doi: 10.1080/24748668.2013.11868690. [CrossRef] [Google Scholar]

30. The German Environment Agency Official Webpage. [(accessed on 30 October 2021)]. Available online: www.umweltbundesamt.de

31. Tainio M., Andersen Z.J., Nieuwenhuijsen M.J., Hu L., de Nazelle A., An R., Garcia L.M., Goenka S., Zapata-Diomedi B., Bull F., et al. Air pollution, physical activity and health: A mapping review of the evidence. Environ. Int. 2020;147:105954. doi: 10.1016/j.envint.2020.105954. [PMC free article] [PubMed] [CrossRef] [Google Scholar]

32. The Main Inspectorate of Environmental Protection Official Webpage. [(accessed on 30 October 2021)]; Available online: www.gios.gov.pl

33. Kobza J., Geremek M., Dul L. Characteristics of air quality and sources affecting high levels of PM10 and PM2.5 in Poland, Upper Silesia urban area. Environ. Monit. Assess. 2018;190:515. doi: 10.1007/s10661-018-6797-x. [PMC free article] [PubMed] [CrossRef] [Google Scholar]

34. Deutsche Fußball Liga (DFL) Definitionskatalog Offizielle Spieldaten–Bundesliga Website. [(accessed on 6 June 2019)]. Available online: https://s.bundesliga.com/assets/doc/10000/2189_original.pdf (accessed 20/8/23)

35. Cohen J. Statistical Power Analysis for the Behavioral Sciences. 2nd ed. Routledge; New York, NY, USA: 1988. [Google Scholar]

36. El Helou N., Tafflet M., Berthelot G., Tolaini J., Marc A., Guillaume M., Hausswirth C., Toussaint J.-F. Impact of Environmental Parameters on Marathon Running Performance. PLoS ONE. 2012;7:e37407. doi: 10.1371/journal.pone.0037407. [PMC free article] [PubMed] [CrossRef] [Google Scholar]

37. Strak M., Boogaard H., Meliefste K., Oldenwening M., Zuurbier M., Brunekreef B., Hoek G. Respiratory health effects of ultrafine and fine particle exposure in cyclists. Occup. Environ. Med. 2009;67:118–124. doi: 10.1136/oem.2009.046847. [PubMed] [CrossRef] [Google Scholar]

38. FIFA Official Webpage. [(accessed on 30 October 2021)]. Available online: www.fifa.com

39. Barnes C., Archer D.T., Hogg B., Bush M., Bradley P.S. The Evolution of Physical and Technical Performance Parameters in the English Premier League. Int. J. Sports Med. 2014;35:1095–1100. doi: 10.1055/s-0034-1375695. [PubMed] [CrossRef] [Google Scholar]

40. Konefał M., Chmura P., Zając T., Chmura J., Kowalczuk E., Andrzejewski M. A New Approach to the Analysis of Pitch-Positions in Professional Soccer. J. Hum. Kinet. 2019;66:143–153. doi: 10.2478/hukin-2018-0067. [PMC free article] [PubMed] [CrossRef] [Google Scholar]

41. Duda H., Rydzik Ł., Czarny W., Błach W., Görner K., Ambroży T. Reaction of the Organisms of Young Football Players to City Smog in the Sports Training. Int. J. Environ. Res. Public Health.

2020;17:5510. doi: 10.3390/ijerph17155510. [PMC free article] [PubMed] [CrossRef] [Google Scholar]

42. Pinkerton K.E. Distribution of particulate matter and tissue remodeling in the human lung. Environ. Health Perspect. 2000;108:1063–1069. doi: 10.1289/ehp.001081063. [PMC free article] [PubMed] [CrossRef] [Google Scholar]

43. Goodman J.E., Chandalia J.K., Thakali S., Seeley M. Meta-analysis of nitrogen dioxide exposure and airway hyper-responsiveness in asthmatics. Crit. Rev. Toxicol. 2009;39:719–742. doi: 10.3109/10408440903283641. [PubMed] [CrossRef] [Google Scholar]

44. Münzel T., Gori T., Al-Kindi S., Deanfield J., Lelieveld J., Daiber A., Rajagopalan S. Effects of gaseous and solid constituents of air pollution on endothelial function. Eur. Heart J. 2018;39:3543–3550. doi: 10.1093/eurheartj/ehy481. [PMC free article] [PubMed] [CrossRef] [Google Scholar]

45. Ferdinands J.M., Crawford C.A.G., Greenwald R., Van Sickle D., Hunter E., Teague W.G. Breath acidification in adolescent runners exposed to atmospheric pollution: A prospective, repeated measures observational study. Environ. Health. 2008;7:10. doi: 10.1186/1476-069X-7-10. [PMC free article] [PubMed] [CrossRef] [Google Scholar]

46. Wojdat M., Stańczyk A., Gielerak G. Zanieczyszczenia powietrza a choroby układu sercowo-naczyniowego—niedoceniany problem. Lek. Wojsk. 2016;1:10–16. [Google Scholar]

47. Rowe D.B. Green roofs as a means of pollution abatement. Environ. Pollut. 2011;159:2100–2110. doi: 10.1016/j.envpol.2010.10.029. [PubMed] [CrossRef] [Google Scholar]

48. Nowak D.J., Crane D.E., Stevens J.C. Air pollution removal by urban trees and shrubs in the United States. Urban For. Urban Green. 2006;4:115–123. doi: 10.1016/j.ufug.2006.01.007. [CrossRef] [Google Scholar]

49. DeWolfe J., Waliczek T., Zajicek J. The Relationship between Levels of Greenery and Landscaping at Track and Field Sites, Anxiety, and Sports Performance of Collegiate Track and Field Athletes. HortTechnology. 2011;21:329–335. doi: 10.21273/HORTTECH.21.3.329. [CrossRef] [Google Scholar]

50. Yang J., Yu Q., Gong P. Quantifying air pollution removal by green roofs in Chicago. Atmos. Environ. 2008;42:7266–7273. doi: 10.1016/j.atmosenv.2008.07.003. [CrossRef] [Google Scholar]

51. Oxygencity Official Webpage. [(accessed on 20/8/23)]. Available online: http://www.oxygencity.pl

52. Gonçalves L.G.C., Clemente F., Vieira L.H.P., Bedo B., Puggina E.F., Moura F.A., Mesquita F., Santiago P.R.P., Almeida R., Aquino R. Effects of match location, quality of opposition, match outcome, and playing position on load parameters and players' prominence during official matches in professional soccer players. Hum. Mov. 2021;22:35–44. doi: 10.5114/hm.2021.100322. [CrossRef] [Google Scholar]

Evidence WR LTFC d

- **Can Professional Football Players Adapt to Air Pollution? Evidence From China** https://journals.sagepub.com/doi/abs/10.1177/15270025211049793?journalCode=jsea (accessed 20/8/23)

Sage Journals Home

Search this journal

Enter search terms...

Enter search terms...

Advanced search

Access/Profile

Cart

Browse by discipline

Information for

Journal of Sports Economics

North American Association of Sports Economists

Impact Factor: 1.7 / 5-Year Impact Factor: 2.1

Restricted access

Research article

First published online December 3, 2021

Can Professional Football Players Adapt to Air Pollution? Evidence From China

Yu Qin, Jing Wu https://orcid.org/0000-0003-0272-0784 (accessed 20/8/23), and Rongjie Zhang [redacted]@mails.tsinghua.edu.cnView all authors and affiliations

Volume 23, Issue 3

https://doi.org/10.1177/15270025211049793 (accessed 23/8/23).

Abstract

In this paper, we study the impact of air pollution on Chinese professional football players' performance. Our primary research question is whether the negative effects of air pollution can be mitigated by adaptation, and which cohort of players can have higher adaptability. We find that a higher pollution level during the game, relative to the adapted pollution level in players' home cities, has a negative and significant impact on the players' efforts and accuracy. The impact of non-adapted air pollution can be greatly offset by the home advantage, but not by personal attributes such as the higher ability.

References

Archsmith J., Heyes A., Saberian S. (2018). Air quality and error quantity: Pollution and performance in a high-skilled, quality-focused occupation. Journal of the Association of Environmental and Resource Economists, 5(4), 827–863. https://doi.org/10.1086/698728 (accessed 20/8/23)

Google Scholar

Beatty T., Shimshack J. (2014). Air pollution and children's Respiratory health: A cohort analysis. Journal of Environmental Economics and Management, 67(1), 39–57. https://doi.org/10.1016/j.jeem.2013.10.002 (accessed 20/8/23)

Google Scholar

Carling C., Williams A., Reilly T. (2005). Handbook of soccer match analysis. Routledge.

Crossref

Google Scholar

Chang T., Graff Zivin J., Gross T., Neidell M. (2019). The effect of pollution on worker productivity: Evidence from call center workers in China. American Economic Journal: Applied Economics, 11(1), 151–172. https://doi.org/10.1257/app.20160436 (accessed 20/8/23)

Google Scholar

Deryugina T., Heutel G., Miller N., Molitor D., Reif J. (2019). The mortality and medical costs of air pollution: Evidence from changes in wind direction. American Economic Review, 109(12), 4178–4219. https://doi.org/10.1257/aer.20180279 (accessed 20/8/23)

PubMed

Google Scholar

Graff Zivin J., Neidell M. (2012). The impact of pollution on worker productivity. American Economic Review, 102(7), 3652–3673. https://doi.org/10.1257/aer.102.7.3652

PubMed

Google Scholar

Graff Zivin J., Neidell M. (2018). Air pollution's Hidden impacts. Science (New York, NY), 359(6371), 39–40. https://doi.org/10.1126/science.aap7711

Google Scholar

Grothmann T., Patt A. (2005). Adaptive capacity and human cognition: The process of individual adaptation to climate change. Global Environmental Change, 15(3), 199–213. https://doi.org/10.1016/j.gloenvcha.2005.01.002

Google Scholar

Guo J., Zhang X., Gu F., Zhang H., Fan Y. (2020). Does air pollution stimulate electric vehicle sales? Empirical evidence from twenty major cities in China. Journal of Cleaner Production, 249, 119372. https://doi.org/10.1016/j.jclepro.2019.119372

Google Scholar

Guo M., Fu S. (2019). Running with a mask? The effect of air pollution on marathon runners' performance. Journal of Sports Economics, 20(7), 903–928. https://doi.org/10.1177/1527002518822701

ISI

Google Scholar

Hackney J., Linn W., Mohler J., Collier C. (1977). Adaptation to short-term respiratory effects of ozone in men exposed repeatedly. Journal of Applied Physiology, 43(1), 82–85. https://doi.org/10.1152/jappl.1977.43.1.82

PubMed

Google Scholar

Hamade A., Tankersley C. (2009). Interstrain variation in cardiac and respiratory adaptation to repeated ozone and particulate matter exposures. American Journal of Physiology-Regulatory, Integrative and Comparative Physiology, 296(4), 1202–1215. https://doi.org/10.1152/ajpregu.90808.2008

Google Scholar

Han L., Zhou W., Li W., Li L. (2014). Impact of urbanization level on urban air quality: A case of fine particles (PM2.5) in Chinese cities. Environmental Pollution, 194, 163–170. https://doi.org/10.1016/j.envpol.2014.07.022

PubMed

Google Scholar

Hao Y., Liu Y. (2016). The influential factors of urban PM2.5 concentrations in China: A spatial econometric analysis. Journal of Cleaner Production, 112, 1443–1453. https://doi.org/10.1016/j.jclepro.2015.05.005

Google Scholar

He J., Liu H., Salvo A. (2019). Severe air pollution and labor productivity: Evidence from industrial towns in China. American Economic Journal: Applied Economics, 11(1), 173–201. https://doi.org/10.1257/app.20170286

Google Scholar

Hochachka P. (1998). Mechanism and evolution of hypoxia-tolerance in humans. Journal of Experimental Biology, 201(8), 1243–1254. https://doi.org/10.1242/jeb.201.8.1243

PubMed

Google Scholar

Hoffmann A., Sgrò C. (2011). Climate change and evolutionary adaptation. Nature, 470(7335), 479–485. https://doi.org/10.1038/nature09670

PubMed

Google Scholar

Klingen J., Ommeren J. (2020). Risk attitude and air pollution: Evidence from chess. Tinbergen Institute Discussion Papers 2020-027/VIII, Tinbergen Institute. https://ssrn.com/abstract=3609237

Crossref

Google Scholar

Lichter A., Pestel N., Sommer E. (2017). Productivity effects of air pollution: Evidence from professional soccer. Labour Economics, 48, 54–66. https://doi.org/10.1016/j.labeco.2017.06.002

Google Scholar

Liu H., Lu J., Salvo A. (2019). Willingness to fight on: Environmental valuation in dynamic competitions. Working paper.

Google Scholar

Mäkinen T. (2007). Human cold exposure, adaptation, and performance in high latitude environments. American Journal of Human Biology, 19(2), 155–164. https://doi.org/10.1002/ajhb.20627

PubMed

ISI

Google Scholar

Moore L. (2000). Comparative human ventilatory adaptation to high altitude. Respiration Physiology, 121(2-3), 257–276. https://doi.org/10.1016/S0034-5687(00)00133-X

PubMed

Google Scholar

Pollard R. (2002). Evidence of a reduced home advantage when a team moves to a new stadium. Journal of Sports Sciences, 20(12), 969–973. https://doi.org/10.1080/026404102321011724

PubMed

Google Scholar

Ven N. (2011). Supporters are not necessary for the home advantage: Evidence from same-stadium derbies and games without an audience. Journal of Applied Social Psychology, 41(12), 2785–2792. https://doi.org/10.1111/j.1559-1816.2011.00865.x

Google Scholar

Waters A., Lovell G. (2002). An examination of the homefield advantage in a professional English soccer team from a psychological standpoint. Football Studies, 5(1), 46–59. https://www.mendeley.com/catalogue/b8ba0122-bd13-3725-a6a3-1cdbea9017d7/

Google Scholar

Xie Y., Dai H., Dong H., Hanaoka T., Masui T. (2016). Economic impacts from PM2.5 pollution-related health effects in China: A provincial-level analysis. Environmental Science & Technology, 50(9), 4836–4843. https://doi.org/10.1021/acs.est.5b05576

PubMed

Google Scholar

Biographies

Yu Qin, Associate professor, Department of Real Estate, National University of Singapore, Singapore.

Jing Wu, Associate professor, Hang Lung Center for Real Estate, Department of Construction Management, Tsinghua University, Beijing, China.

Rongjie Zhang, PhD student, Hang Lung Center for Real Estate, Department of Construction Management, Heshanheng Building, Tsinghua University, Beijing 100084, China. Email: [redacted]@mails.tsinghua.edu.cn.

Evidence WR LTFC e

Evidence WR LTFC e

- **Exercise and outdoor ambient air pollution**
  https://bjsm.bmj.com/content/35/4/214 (accessed 20/8/23)

Exercise and outdoor ambient air pollution FREE

A J Carlisle1, N C C Sharp2

Correspondence to: Ms Carlisle, University of Surrey Roehampton, School of Sport Exercise and Leisure, Whitelands College, West Hill, London SW15 3SN, UK [redacted]@roehampton.ac.uk

Abstract

Objectives—To establish by literature survey: (a) levels at which air pollutants are considered damaging to human health and to exercisers in particular; (b) the current ambient levels experienced in the United Kingdom; (c) whether athletes are especially at risk.

Methods—Six major urban air pollutants were examined: carbon monoxide (CO); nitrogen oxides (NOX); ozone (O3); particulate matter (PM10); sulphur dioxide (SO2); volatile organic compounds (VOCs).

Results—CO is detrimental to athletic performance. NO2 is of concern to human health, but outdoor levels are low. O3 poses a potentially serious risk to exercising athletes. Decrements in lung function result from exposure, and there is evidence that athletic performance may be affected. Detrimental effects may occur at low ambient levels, but there is no scientific consensus on this matter. PM10 is causing concern in the scientific community. Blood lead accumulation during exercise indicates that personal exposure to toxic compounds associated with PM10 may be magnified. Generally, outdoor ambient levels of SO2 are too low to cause a problem to the athlete, except the asthmatic athlete. The few studies on exposure of exercisers to VOCs are reviewed.

Conclusions—Athletes and exercisers should avoid exercising by the road side even though levels of the more noxious air pollutants have been controlled in the United Kingdom. O3 is particularly damaging to athletes; it reaches its highest concentrations on hot bright days in rural areas.

Take home message

The respiratory physiology of exercise suggests that athletes and other exercisers may experience magnified exposure to ambient air pollution.

http://dx.doi.org/10.1136/bjsm.35.4.214 (accessed 20/8/23 links back to bmj url)

Air pollution continues to be a matter for concern despite falling levels of some of the major pollutants. The aim of this review is to examine six major pollutants in relation to exercise: carbon monoxide (CO); nitrogen oxides (NOx); ozone (O3), particulate matter (PM10); sulphur dioxide (SO2); volatile organic compounds (VOCs). Many of the effects of air pollution on human health have long been established, but no clear consensus has been reached on the effects of ambient air pollution on the exercising athlete and sport performance. A second aim of this review is to relate current ambient air pollution levels to exercising subjects. Maynard1 identified a need to understand the effects of long term exposure to current concentrations of air pollutants, and a need to identify groups of the population with greater than average sensitivity to them. As a result of the physiological changes that occur during endurance exercise, it has been postulated that endurance athletes may have greater than average susceptibility and exposure to air pollutants.

Three reasons why athletes are at special risk of inhaling pollutants have been put forward by McCafferty.[2] Firstly, there is a proportionate increase in the quantity of pollutants inhaled with increases in minute ventilation ($\dot{V}E$) during exercise. Secondly, a larger fraction of air is inhaled through the mouth during exercise, effectively bypassing the normal nasal mechanisms for the filtration of large particles and soluble vapours. Thirdly, the increased airflow velocity carries pollutants deeper into the respiratory tract. Furthermore, pulmonary diffusion capacity has been shown to increase with exercise[3–6]; it may therefore be postulated that the diffusion of pollutant gases increases with exercise. For several days after strenuous exercise, nasal mucociliary clearance has been shown to be impaired in long distance runners,[7] and this is possibly attributable to exposure to air pollution, as stressed by Atkinson.[8] It could be speculated that such reduced mucociliary clearance may be another contributing factor to the susceptibility of endurance athletes to air pollution, as pollutants that are normally cleared from the respiratory system are instead absorbed.

Inhaled gases can be divided into those that simply equilibrate across the lung—for example, CO—and those that react with components of the respiratory system—for example, O_3. The Department of Health's Committee on the Medical Effects of Air Pollutants (COMEAP)[9] identified the uptake of equilibrating gases as determined by three factors: gas solubility in the blood; cardiac output; the concentration difference between the alveolar space and venous blood, which is dependent on the inhaled concentration of the gas and the ventilation rate. A number of important controlling factors determine the uptake of reactive gases in the lung: morphology; physicochemical properties of the gas, tissues, blood, and mucous; pattern of breathing (nasal/oral or oral); ventilatory rate and tidal volume; convective and diffusional patterns of the gas. Clearly, in the absorption of both equilibrating and reactive gases, a number of factors are altered during exercise: cardiac output; pattern of breathing; ventilatory rate; tidal volume; thickness of mucous layer of the lung; possibly gas diffusion patterns.

Table 1⇓ shows the upper exposure limits (or "standards" as they are referred to in the UK National Air Quality Strategy[10]) of the major air pollutants in the United Kingdom. In the sections that follow, these will be examined and, where possible, illustrations given of the levels commonly experienced in the United Kingdom (particularly London) and how they may relate to someone who is exercising, both in terms of possible health effects and decrements in athletic performance. The weighting given to each section generally reflects both the severity of the problem and the quantity of research published. Units throughout this review are reported in line with the upper exposure limits as outlined in table 1⇓. The standards are concentrations over a given period of time, which if exceeded are considered to be unacceptable in terms of human health and/or the environment.

VIEW INLINE VIEW POPUP

Table 1

Summary of upper exposure limits of the UK National Air Quality Strategy[10]

Carbon monoxide

CO is a colourless and odourless toxic gas which causes hypoxia by various mechanisms: (a) by the formation of carboxyhaemoglobin (COHb) with an affinity that is 200 times greater than oxygen; (b) by decreasing the delivery of oxygen to the tissues (the haemoglobin oxygen dissociation curve shifts to the left); (c) by inhibiting the action of cytochrome oxidases. Variations in uptake of CO are thought to be due to physiological variables such as lung capacity, diffusion constant of the lung, and dead space volume.11 Ventilation rate is also thought to affect CO uptake. In the 1980s, the concentration of COHb in the blood of city dwellers was found to be approximately double that in people living in rural traffic-free areas.11 Strenuous exercise in heavy traffic for 30 minutes can increase the level of COHb 10-fold, which is the equivalent of smoking 10 cigarettes.12

There is no doubt that CO is detrimental to athletic performance and there is much experimental evidence of this.12–18 With CO in the bloodstream, less O2 is released from haemoglobin to myoglobin, and therefore, to compensate, the heart must work harder and beat more frequently. Maximum cardiac output and maximal arteriovenous difference are lowered, resulting in a decrease in maximum oxygen uptake (V̇O2MAX) and work output.19 The formation of COHb is reversible, and exposure to clean air removes most of the gas from the body, with a half life of three to four hours.

The risk of CO poisoning in joggers and cyclists in areas of traffic congestion is difficult to predict because the concentration and movement of CO depend on prevailing wind and temperature. Nonetheless, one study found levels of 4–6% COHb in the blood of city joggers and cyclists, a level comparable to that found in chronic cigarette smokers17 and known to result in decreased exercise tolerance.20 The effects of raised COHb on exercise performance have indicated a significantly lower V̇O2MAX, anaerobic threshold, and oxygen pulse (V̇O2/heart rate), and a significantly higher heart rate and pulse pressure.15 The rate of COHb formation in exercising humans exposed to CO was studied to improve prediction of CO poisoning.14 The existing prediction model, known as the CFK equation (developed by Coburn et al21), was tested and found to be useful overall, with a sigmoidal rate of appearance of COHb as previous observations indicated.14

The World Health Organisation (WHO) calculated the relation between CO concentration and blood COHb for a lightly exercising subject (table 2⇓). COHb values are reduced by a factor of two for a person at rest and increased by a similar factor by heavy exercise. Thus a heavily exercising subject can expect to have 1.6% COHb after one hour in 20 ppm CO. Levels of 2.7% COHb and upwards result in evidence of impaired behaviour.22

VIEW INLINE VIEW POPUP

Table 2

Carbon monoxide health effects for a lightly exercising person22

In the past, accumulated levels of CO posed a significant health risk to athletes in this country, and one of us noted incidents of collapse in London to Brighton relay races in the 1950s. CO levels experienced in the United Kingdom today have been improved by the use of catalytic converters in motor vehicles, which oxidise vehicular exhaust CO to CO_2. The improvement has been offset by the increase in the total number of motor vehicles, so overall total emissions have remained relatively stable in recent years. The UK National Monitoring Network notes that levels of CO are low (fig 1⇓), and the standard for CO (10 ppm eight hour running mean) was seldom exceeded in 1997. Continual monitoring does show high momentary peaks in CO concentration, hence it is prudent always to train away from roads. For comparison, mean (SE) levels of 13.8 (1.7) ppm have been reported inside a car, 44.0 (7.3) ppm in an underground car park, and 10.9 (0.9) ppm in a public house.23

Figure 1

Download figure

Open in new tab

Download powerpoint

Figure 1

Arithmetic mean and maximum hourly average monthly statistics of 1997 CO levels at four British sites from the UK National Monitoring Network10: S, suburban; UB, urban background; CU, central urban; UI, urban industrial.

Nitrogen oxides

The two principle oxides of nitrogen, NO and NO_2, are often considered together and known as NO_x (pronounced “knocks”), despite their quite different physical properties, chemical affinities, and environmental impacts. The main source of NO_x is road traffic. NO is photochemically oxidised to NO_2, and the following photochemical equilibrium exists between the relevant gases: $NO + O_3 \rightarrow NO_2 + O_2$

Of the two oxides of nitrogen, NO_2 has a much higher toxicity. Its distribution has been shown to follow the expected pattern—that is, areas of the United Kingdom with high NO_2 concentrations correlate well with the geographical distribution of the major urban conurbations and major emission sources.22 Discussion will focus on NO_2 in this section.

NO_2 is of concern to human health as it is soluble and can be absorbed by the mucous lining of the nasopharyngeal cavity, where it is converted to nitrous and nitric acids. The oxidant properties of NO_2 after acute exposure at levels of 5000–10 000 ppb can cause respiratory illness, such as pharyngeal irritation, cough, and dyspnoea.11 Resistance to respiratory infection can also be impaired by NO_2 exposure below 500 ppb.11 NO_2 levels in urban environments are usually below 150 ppb. The UK National Air Quality standard for NO_2 is 150 ppb, measured as an hourly mean. Figure 2⇓ illustrates the 1997 monthly statistics for NO_2 from the National Monitoring Network. Long term exposure may have a subtle effect on children. A meta-analysis of 11 epidemiological studies suggested that the chance of infection in the lower respiratory tract may be 20% greater for children with prolonged exposure to NO_2 at a concentration of 16 ppb.20 Asthmatics have been shown to experience significant increases in airway resistance with short term NO_2 exposures of around 500 ppb. Non-asthmatics experience the same changes at NO_2 levels of about 1000 ppb.11 Four daily sequential exposures to 2 ppm NO_2 for four hours resulted in persistent neutrophilic inflammation in the airways of healthy non-smoking subjects. Changes in pulmonary function attenuated with repeated exposures.24 Potentially serious effects may occur, but it has generally been found that outdoor levels are low; there can be greater danger from some indoor environments such as gas heated homes and poorly ventilated residences inside which fires are lit such as are found in underdeveloped countries.

Figure 2

Download figure

Open in new tab

Download powerpoint

Figure 2

Arithmetic mean and maximum hourly average monthly statistics of 1997 NO_2 levels at four British sites from the UK National Monitoring Network10: S, suburban; UB, urban background; CU, central urban; R, rural.

Ozone

O_3 forms in the atmosphere through very complex chemical interactions and equilibria between hundreds of different hydrocarbons and radicals and NO and NO_2, all requiring photochemical energy. Daily ambient O_3 levels in the United Kingdom rarely exceed 100 ppb,9 at which concentration significant decrements in lung function (forced vital capacity (FVC); forced expiratory volume in one second (FEV_1); mean forced expiratory flow between 25 and 75% of FVC ($FEF_{25–75}$); airway resistance (RAW)) have been observed at an exercise intensity equating to a $\dot{V}E$ of 70.0 litres/min.25 Figure 3⇓ shows monthly statistics for O_3 in 1997. As expected, O_3 levels were higher in the summer than the winter. In large hot cities such as Los Angeles, a diurnal pattern of O_3 concentration is observed, peaking around midday well after the morning rush hour and when solar radiation is at its highest. O_3, however, is a transboundary pollutant and travels considerable distances. As such, and contrary to conventional wisdom, it is predominantly a rural pollutant.

Figure 3

Download figure

Open in new tab

Download powerpoint

Figure 3

Arithmetic mean and maximum hourly average monthly statistics of 1997 O_3 levels at four British sites from the UK National Monitoring Network10: S, suburban; UB, urban background; CU, central urban; R, rural.

O_3 exposure above 120 ppb is known to have detrimental effects on health. Symptoms are nose and throat irritation, coughing, wheezing, shortness of breath, and an inability to take deep breaths because of substernal chest pain or constriction. Nausea and headache occur if O_3 exposure is sufficient. Abnormalities of pulmonary function usually parallel the severity of symptoms and are accelerated by exercise. Data obtained in the 1970s and 1980s confirm the observation that decreased FVC and FEV_1 are consistent responses to O_3 exposure. FVC and FEV_1 are easily measured and yield quantifiable results. Concentration-response regression curves of lung measurements in exercising subjects show progressively increased decrements in measurements of lung function with increasing exercise intensity.25 Other forced and inspired flow rates, inspiratory capacity and total lung capacity (TLC), are also affected, and there is increased RAW and residual volume.

It has been suggested that O_3 inhalation stimulates receptors located in the smooth muscle layers of the upper airways.26 Contraction of the inspiratory muscles is limited by the non-myelinated C fibre afferent nerves of vagal origin, which may act through axonal reflex connections or through spinal reflexes. The net effect on the human lung is involuntary inhibition of full inspiration, reduction of transpulmonary pressure and inspiratory capacity, and increased flow resistance. There is an associated decrease in maximal expiratory flow rates, TLC, and vital capacity accompanied by substernal pain and coughing. Research has shown an influx of inflammatory cells into the pulmonary tissue.27 Pretreatment with ibuprofen has been shown to alleviate symptoms produced by O_3 exposure.27 Folinsbee28 points out that some research has shown that pretreatment with the cyclo-oxygenase inhibitor indometacin abolishes O_3 induced decrements in pulmonary function. Pretreatment with salbutamol has been found to be ineffective in reducing or eliminating pulmonary discomfort or respiratory dysfunction in cyclists exposed to O_3.29 This observation on exercising subjects has been supported elsewhere.26 The decreased tidal volume and increased respiratory rate associated with O_3 exposure cause relative hyperventilation. High environmental temperature (35°C) has been shown to exacerbate further the negative impact of O_3 on lung function.30, 31

Athletes are vulnerable to the effects of inhaled O_3 because of their exercise patterns.31$\dot{V}E$ and $\dot{V}O_2$ are both dramatically increased with the onset of physical activity, whether it is heavy short term or less intense and prolonged, including training, warm up, and competition. Long distance runners perform at exercise intensities as great as 90% of their $\dot{V}O_{2MAX}$, which may correspond to a $\dot{V}E$ of over 100 litres/min, and they may maintain this for over an hour. Elite endurance cyclists may similarly maintain a $\dot{V}E$ of 80 litres/min during hour long races. Resting $\dot{V}E$ is by comparison <10 litres/min. There is high individual variability in response to O_3 exposure, showing that the effects of O_3 are a consequence of multiple factors within the pulmonary tree.28 Many studies were published in the 1960s, 1970s, and 1980s and have been reviewed elsewhere31.

The respiratory discomfort associated with O_3 exposure may cause decreased maximal work performance. Ten highly trained endurance athletes were randomly exposed to filtered air, and to 0.12, 0.18, and 0.24 ppm O_3 while performing a one hour competitive simulation protocol on a cycle ergometer.32 They all completed the protocol when exposed to filtered air, whereas one, five, and seven subjects did not complete the protocol when exposed to 0.12, 0.18, and 0.24 ppm (120, 180, and 240 ppb) O_3 respectively. Statistical analysis indicated a significant ($p<0.05$) increase in the inability of subjects to complete the competitive simulations with increasing O_3 exposure when compared with filtered air. There was also a significant and progressive decrement in pulmonary function. Respiratory discomfort has been observed to contribute significantly to an increase in overall relative perceived exertion.33 Furthermore, the increased breathing frequency and decreased tidal volume associated with O_3 exposure has been postulated to be behavioural, as it reduces the sensation of pain.28 A physiological mechanism is involved: O_3 stimulates the non-myelinated bronchial C fibres involved in the reflex which changes breathing patterns to rapid and shallow breathing.28 It is possible that people become habituated to O_3 and that acclimatisation by athletes may occur.

Levels of O_3 lower than 60 ppb have been shown to significantly affect lung function.34 FVC, FEV_1, $FEF_{25–75}$, and peak expiratory flow rate were recorded before and after exercise in healthy young men. Data were collected in the field and related to O_3 concentrations obtained from the nearest stations of the National Monitoring Network. O_3 concentrations were low, with an average of 43 ppb and a maximum of 97 ppb. Results of the study show that there was a significant association between O_3 and a decline in lung function over a race or training period. Other confounding environmental factors, such as temperature, PM_{10}, SO_2, and NO_2, were considered. Temperature, it was argued, did not magnify the alterations in lung function observed in this study, as 80% of the data were obtained at a temperature below 22°C. Concentrations of SO_2 and NO_2 were low during the period of observation and it was considered unlikely that they had any confounding effects. No ambient air levels of PM_{10} were available, so no adjustment could be made. These observations, coupled with the finding that the removal of data obtained at O_3 concentrations higher than 60 ppb still left significant effects, were taken as an indication that O_3 at very low concentrations resulted in changes in lung function during exercise. However, this observation is not supported by other studies,25, 31, 35 in which the maximum length of exposure was two hours, the studies were conducted in pollution chambers, O_3 was studied singly, and cumulative effects were not looked for. It therefore seems likely that the findings of Brunekreef et al34 are more reflective of ambient exposure, although it is questionable whether the decrements in lung function would surface as decrements in exercise performance.

O_3 is an unpleasant gas, and its effects are detrimental to athletic performance if exposure is sufficiently high. Levels of O_3 experienced in the United Kingdom, however, remain low most of the time, and therefore O_3 is unlikely to cause problems here. The outlook in this country is that O_3 levels will increase by about 3–4 ppb from current levels of around 10–15 ppb.36

Particulate matter

Particulate matter comprises solid (soluble or insoluble) or liquid material present in the air in particles small enough to remain in suspension for some hours or days. They are typically less than 10 µm in diameter and are therefore often referred to as PM_{10}. Particles of this size are capable of entering the respiratory tract and reaching the deeper parts of the lung. A significant proportion of PM_{10} is less than 2.5 µm in diameter ($PM_{2.5}$), and it is particles of this size that are most likely to be deposited in the respiratory tract, and, once in the alveoli, diffusive deposition increases. Particles of diameter of less than 0.5 µm are least likely to be deposited in the respiratory tract, as they are too small to either impact on, or diffuse to, the walls effectively and are exhaled before they can be deposited.

Particulate pollution peaks during smogs. Winter smogs are a result of build up of local emissions in cold still weather, and summer smogs are caused by the action of sunlight on emissions accompanied by a build up of O_3. There is a synergistic interaction between PM_{10}, SO_2, and water vapour.22 Water vapour and SO_2 are absorbed on to soot particles while they are present together in the ambient air, and trace metals such as vanadium in the particles catalyse the formation of sulphuric acid. On inhalation, these particles transport the sulphuric acid deep into the lungs, where the gas exchange surfaces are damaged and the capacity for oxygen exchange is decreased. This synergism between particles and SO_2 is such that it has been incorporated into legislation, with recommendations for lower tolerable levels of SO_2 when the particulate levels are above a certain concentration: the European Community, for example, specifies an annual mean of 120 µg/m3 SO_2 unless the particle concentration is less than 40 µg/m3, when the upper limit for SO_2 is reduced to 80 µg/m3.

During the 1990s in the United States and Canada, very many studies indicated a link between airborne particulate matter and mortality.37 In response to growing concern in the United Kingdom on this matter, the government invited COMEAP to advise on the health effects of non-biological particles,38 and the Expert Panel on Air Quality Standards (EPAQS) to recommend air quality standards for particles.39 The recommended upper limit of PM10 is currently 50 µg/m3 as a running 24 hour average in the United Kingdom, which is seldom exceeded in London, where smoke control exists, as illustrated by fig 4⇓. In areas of Britain where there is no smoke control, high levels could build up in the winter months when temperature inversion occurs. COMEAP's report on non-biological particles and health recognised that exercise may have a variable effect on particle deposition depending on particle size and pattern of respiration.38 It may be that, at increased airflow velocities, the pollutants are not deposited but simply exhaled. As yet the question of pollutant deposition in the respiratory tract during exercise remains unanswered and uncertain. What is certain is that the increased airflow velocity (a consequence of pronounced increases in V̇E) bypasses much of the normal nasal filtration and carries pollutants deeper into the respiratory tract; hence there is a proportionate increase in the quantity of pollutants inhaled.

Figure 4

Download figure

Open in new tab

Download powerpoint

Figure 4

Arithmetic mean and maximum hourly average monthly statistics of 1997 levels of particulate matter (PM10) at four British sites from the UK National Monitoring Network10: S, suburban; UB, urban background; CU, central urban; R, rural.

There have been very few studies examining the relation between exercise and PM10 inhalation. Personal sampling of PM10 pollution in a group of people working close to traffic has shown it to be significantly higher than static measurements of area,40 and from this it can be surmised that the same would be true for athletes training by the roadside. Weather conditions have a pronounced effect on PM10 exposure—for example, rainy weather and high wind speeds result in lower PM10 concentrations.41, 42 Equipment for personal air sampling was supplied to volunteers in a study on exposure of cyclists, car drivers, and pedestrians in Amsterdam to pollution.41 Thoracic fraction PM10 was monitored, and within this fraction the content of lead and six (carcinogenic) polyaromatic hydrocarbons was determined. A comparison was made between rural and inner city routes. Table 3⇓ shows the results for PM10. PM10 concentration was on average about seven times lower on a quiet open rural route than on an inner city route. Similar results were gained from a study on commuting by bicycle in Southampton.42 The findings of these two studies indicate that personal exposure to PM10 of people exercising at the roadside in the city is higher than that of the sedentary person and those exercising in rural locations. Although this is unlikely to affect athletic performance, it has potentially significant effects on health. Exposure to human carcinogens associated with PM10 is considered negligible by the UK government.38

VIEW INLINE VIEW POPUP

Table 3

One hour averaged results for concentrations of particulate matter of diameter less than 10 µm (PM10) by route41

Lead is associated with particulates. After inhalation, it is absorbed into the bloodstream with potentially toxic effects on a wide range of body tissues.43 Figure 5⇓ presents the results of a South African study on ultra-marathon runners before and after government legislation halved lead content of petrol. Significant differences were found in mean blood lead level ($p = 0.01$) between the subjects examined in 1984 and 1990, reflecting the fall in lead content of petrol. On average, the blood lead levels in city runners had decreased from 52 to 10 µg/dl of blood (2.5 to 0.5 µmol/l), and the level in rural athletes had decreased from 20 to 8.5 µg/dl. No significant difference was found among the 1990 urban trainers, rural trainers, and urban controls. A significant difference was shown, however, between the 1990 rural trainers and 1984 remote rural controls, the 1990 city trainers and 1984 remote rural controls, and the 1990 controls and 1984 rural trainers.44 This indicates that lead is accumulated faster in runners because of the higher exercising intensity. A study of British competitive cyclists aimed to establish the influence of training environment and racing discipline (time trialists or road racers) on blood lead level.43 No significant difference was found in blood lead level between controls and experimental groups, but this may have been due to the very small sample size. Correlations between blood lead level and training type were examined, and the results indicated that training type influenced blood lead level (table 4⇓).

VIEW INLINE VIEW POPUP

Table 4

Correlation coefficients between blood lead levels and amount of training and racing in each environment for the pooled sample (n=10)43

Figure 5

Download figure

Open in new tab

Download powerpoint

Figure 5

Mean (SD) blood lead level in competitors in the 1984 and 1990 Comrades marathon of South Africa.44

PM10 is inhaled deeper into the respiratory tract during exercise, but, as yet, it is uncertain whether exercise increases deposition. The research on blood lead indicates that lead (which is associated with particulate matter) may accumulate to higher concentrations in people who train in an urban compared with a rural environment. A significant correlation has also been shown between number of training hours and blood lead accumulation. It would seem therefore that runners and cyclists experience increased exposure to lead. Could it be that personal exposure to other toxic compounds associated with PM10 is also increased?

Sulphur dioxide

The effects of SO2 have been clearly documented elsewhere.13, 28, 45 The gas readily dissolves in water and tends to be removed from the inspired air stream by the moist surfaces of the upper airways, especially the nasal mucosa. The threshold level for the effects of SO2 on lung function lies between 1000 and 2000 ppb in normal healthy adults. Above the threshold, resting subjects exposed to SO2 experience bronchospasm. During exercise, as oral breathing replaces nasal breathing, a corresponding increase in penetration of SO2 into the intrathoracic airways exacerbates the effect.45 The inspiration of 5000 ppb SO2 during exercise results in a significantly higher rate of mucociliary clearance than in exercising controls breathing air.13 This is a high dose, and SO2 is unlikely to occur in the UK environment at such a level, but the finding has important implications because mucociliary clearance is an important aspect of the respiratory system's defence against microorganisms and particulate pollution. It is also of note that exercise alone increases the rate of mucociliary clearance. Today's legislation requires clean technological processes, and, in the United Kingdom, SO2 emissions have been reduced to well below the threshold level. The recommended air quality standard in Britain for SO2 is 100 ppb measured over a 15 minute averaging period. Figure 6⇓ shows the monthly statistics for SO2 in 1997.

Figure 6

Download figure

Open in new tab

Download powerpoint

Figure 6

Arithmetic mean and maximum hourly average monthly statistics of 1997 SO2 levels at four British sites from the UK National Monitoring Network10: S, suburban; UB, urban background; CU, central urban; R, rural.

Asthmatics are generally ten times more sensitive to SO_2 than non-asthmatics, especially when exercising. The symptoms associated with asthma are exacerbated by SO_2. At concentrations of 500 ppb SO_2, exercising asthmatics experience pronounced changes (as much as 100%) in airways resistance after as little as five minutes of exercise.[46] Decreases in FEV_1 of 50–60% are seen in most exercising asthmatics exposed to 0.25 ppm SO_2.[28] Wheezing, chest tightness, and dyspnoea are experienced. Fortunately, all the symptoms and changes in lung function associated with exercising in SO_2 can be rapidly reversed by treatment with a β_2 adrenergic agonist—for example, salbutamol or terbutaline. Cromolyn sodium or β-agonists have been used prophylactically.[47] Histamine release from mast cells in the respiratory tissue is stimulated by SO_2. Smooth muscle contraction and increased resistance to expiratory airflow are produced and reflected in measures of FVC and FEV_1. Cromolyn sodium blocks histamine release thereby minimising bronchoconstriction, whereas a β-agonist produces relaxation of airway smooth muscle.

Although SO_2 is clearly an important irritant for exercising asthmatics and may cause problems for the asthmatic athlete, it is unlikely to be of concern to the athlete with normal lungs at current ambient levels. Air temperature and humidity influence the degree of symptoms experienced, with cold dry air producing a faster and more intense response to SO_2 than warm moist air.[18] It is possible that SO_2 may be one of the triggers for exercise induced bronchospasm. The overall incidence of exercise induced bronchospasm across all sports and sexes in a recent survey of Olympic winter sport athletes was reported as 23%.[48]

Volatile organic compounds

The general category of VOCs consists of many chemicals, including non-methane hydrocarbons (for example, alkanes, alkenes, and aromatics), halocarbons (for example, trichloroethylene), and oxygenates (alcohols, aldehydes, and ketones). The emission into the British environment of well over two million tonnes of VOCs per year is similar in magnitude to that of SO_2 and NO_x.[22] There is a preponderance of carcinogens among VOCs—for example, benzene, polyaromatic hydrocarbons, 1,3-butadiene, many of the halocarbons. Owing to the carcinogenicity of benzene and polyaromatic hydrocarbons, no safe levels are recommended by WHO. The published standards of the UK National Air Quality Strategy are 5 ppb for benzene as a running annual mean, and 1 ppb for 1,3-butadiene as a running annual mean (table 1⇑).

The area of exercise and VOCs inhalation and possible accumulation appears to have been largely overlooked, and there are few studies on exposure to VOCs during exercise. Exposure of cycling commuters (average journey time 35 minutes) to various VOCs was studied in Southampton.[42] Eighteen VOCs were identified and quantified. $\dot{V}E$ was not measured, but it was taken into account in the conclusions of the study, and the group recognised it as a significant factor in terms of personal exposure. They found significantly increased levels of exposure to aromatic VOCs, but not to hydrocarbons and other measured VOCs, when commuting by bicycle during peak traffic periods.

Weather conditions affected results, with lower exposure on windy days. In the Netherlands, personal exposure to pollutants was compared in people commuting by car and bicycle by urban and rural routes (average journey time one hour; sampling time 30 minutes).41$\dot{V}E$ was measured continuously with a gas meter, and heart rate was recorded. Ambient air was sampled at a constant flow rate of 1 litre/min through active charcoal tubes. Benzene, toluene, and xylene were analysed by gas chromatography. It was concluded that car drivers are exposed to higher concentrations of VOCs than cyclists, but, because of the magnitude of the increase in $\dot{V}$, uptake of benzene, toluene, and xylene in cyclists sometimes approached that of car drivers. The ratio of urban to rural personal exposure levels was calculated for cyclists, and found to be 1:5 for benzene and toluene, and 1:10 for xylene. Weather patterns affected results; time weighted exposure to VOCs was higher in August for cyclists. The limited data available on VOCs in relation to exercise indicate that cycling in urban areas results in higher personal exposure to VOCs than cycling in rural areas. Extrapolation to runners is probably justified. VOCs are important and often overlooked pollutants, some of which are carcinogens.

Conclusions and advice

Advice to those exercising is of course to stay away from traffic. There is an exponential decline in concentrations of many air pollutants with increasing distance from the busy road. It is advisable to exercise whenever possible in open rural or park land. High momentary peaks can occur in the levels of any of the pollutants. Try to avoid the rush hour when NOx, CO, and VOCs are likely to accumulate. If it is cold and smoggy, exercise indoors. Windy weather tends to dilute and disperse the pollutants. Check the pollution forecasts and bulletins and take heed of any warnings. Particular care is advised when travelling. Some countries do not have the same stringent regulations to control pollution as the United Kingdom, and the air quality could be considerably different as a result. Climatic and geographic conditions can result in much higher accumulations of pollutants, as in Los Angeles, for example, so even in “developed” countries dangerously high pollution levels may occur. Indoor environments pose more risk of CO poisoning than the open road, with higher levels found inside a pub and a car than by a school kerbside.23 Athletes should therefore keep away from smoky environments and avoid car journeys in congested traffic before competition and training, as the temporarily accumulated CO may reach levels that will have detrimental effects on athletic performance. On hot bright days in the United Kingdom, elevated levels of O3 may occur, which can be avoided by running/cycling in the early morning or late evening. Check the pollution bulletins and forecasts for occasional high levels in photochemical smogs during summer inversions. Be especially careful in rural areas where elevated O3 levels may occur. SO2 is unlikely to be of concern to the athlete with normal lungs at current ambient levels, but it clearly is an important irritant for exercising asthmatics, and may cause problems for the asthmatic athlete. Asthmatics are advised to take their (inhaler) medication before exercise, and to carry an inhaler with them when exercising. There is little risk of damage from exposure to NO2 while street training in the London urban atmosphere, although there may be a greater risk in rural areas. The advice above all is to keep away from busy roads.

Diet may be important. There is some evidence from animal studies that vitamin E can prevent some morphological and biochemical effects of O_3 exposure, although there is little supporting evidence from studies on humans.45 A leading authority finds that antioxidant supplements reduce the detrimental effects of O_3, possibly by decreasing formation of lipoperoxides, ozonoides, and oxidation products.28 Recent epidemiological research has found evidence of an interaction between NO_2 exposure and significantly decreased plasma β-carotene levels in supplemented subjects.49 It would be advisable for all athletes to ensure that they consume adequate dietary β-carotene and other antioxidants as fresh vegetables and fruit each day, and/or by taking dietary supplement(s).

Although it is logical to study air pollutants singly, ambient air pollutants do not exist in isolation; they constitute a cocktail, and synergism may exist between them. Environmental conditions and the weather affect levels of pollution exposure and physiological responses. Some studies have shown personal exposure to be significantly different from the levels indicated by ambient monitoring carried out by the local authorities in the United Kingdom. This consideration is highly relevant to the training athlete who may also suffer greater exposure for the reasons outlined in the introduction. The length of time spent exercising is another very important factor. Ultra-marathon runners and others participating in long endurance events—for example, walking and cycling—are likely to be most at risk from the negative and harmful effects of pollution exacerbated by exercise. Future research could be directed at studying the collective effects of pollutants and personal exposure, and the adoption of risk assessment in relation to exposure to air pollution could be a way forward to ensure adequate long term health protection for the athlete.

Rapid responses

Letters on the following papers have been published recently as rapid responses on the BJSM website. To read these letters visit www.bjsportmed.com and click on “Read eLetters”:

Indoor rock climbing: who gets injured? DM Wright, TJ Royle, T Marshall. Br J Sports Med 2001;35:181–5.

Diabetes and extreme altitude mountaineering. K Moore, C Thompson, R Hayes. Br J Sports Med 2001;35:83.

Evidence-based sports medicine. P McCrory. Br J Sports Med 2001;35:79–80.

Methods of appointment and qualifications of club doctors and physiotherapists in English professional football: some problems and issues. I Waddington, M Roderick, R Naik. Br J Sports Med 2001;35:48–53.

Medical supervision of sport diving in Scotland: reassessing the need for routine medical examinations. S Glen, S White, J Douglas. Br J Sports Med 2000;34:375–8.

Getting started—a review of physical activity adoption studies. AL Dunn. Br J Sports Med 1996:30:193–9.

If you would like to post an electronic response to these or any other articles published in the journal, please go to the website, access the article in which you are interested, and click on “eLetters: Submit a reponse to this article” in the box in the top right hand corner.

Acknowledgments

We thank the reviewers for the obvious trouble that was taken with the manuscript, and also Drs Helen Carter and Jonathan Horner for their initial comments on the manuscript.

References

↵Maynard RL. Air pollution research in the United Kingdom. Occup Environ Med1999;56:647.FREE Full TextGoogle Scholar

↵McCafferty WB. Air pollution and athletic performance. Springfield: Charles C Thomas, 1981.

↵Turcotte RA, Perrault H, Marcotte JE, et al. A test for measurement of pulmonary diffusion capacity during high intensity exercise. J Sports Sci1992;10:229–35.PubMedGoogle Scholar

Turcotte RA, Kiteala L, Marcotte JE, et al. Exercise-induced oxyhemoglobin desaturation and pulmonary diffusiong capacity during high-intensity exercise. Eur J Appl Physiol1997;75:425–30.CrossRefGoogle Scholar

Stokes DL, Macintyre NR, Nadel JA. Non-linear increases in diffusing capacity during exercise by seated and supine subjects. J Appl Physiol1981;51:858–63.PubMedWeb of ScienceGoogle Scholar

↵Fisher JT, Cerny FJ. Characteristics of adjustment of lung diffusiong capacity to work. J Appl Physiol1982;52:1124–7.PubMedGoogle Scholar

↵Muns G, Singer P, Wolf F, et al. Impaired nasal muciliary clearance in long-distance runners. Int J Sports Med1995;16:209–13.CrossRefPubMedWeb of ScienceGoogle Scholar

↵Atkinson, G. Air pollution and exercise. Sports Exercise and Injury1997;3:2–8.Google Scholar

↵COMEAP for the DoH. Asthma and air pollutants. London: HMSO, 1995.

↵National Air Quality Information Archives. http://www.aeat.co.uk/netcen/airqual/ (accessed 20/8/23).

↵Lee K, Yanagisawa Y, Spengler JD, et al. Carbon monoxide and nitrogen dioxide exposures in indoor ice skating rinks. J Sports Sci1994;12:279–83.PubMedWeb of ScienceGoogle Scholar

↵Nicholson JP, Case DB. Carboxyhaemoglobin levels in New York City runners. Physician and Sportsmedicine1983;11:135–8.Google Scholar

↵Horvarth S. Impact of air quality on exercise performance. Exerc Sports Sci Rev1981;9:265–96.Google Scholar

↵Tikusis P, Kane DM, McLellan TM, et al. Rate of formation of carboxyhaemoglobin in exercising humans exposed to carbon monoxide. J Appl Physiol1992;72:1311–19.PubMedWeb of ScienceGoogle Scholar

↵Hopkins MG. Passive smoking as determined by salivary cotinine and plasma carboxyhaemoglobin levels in adults and school-aged children of smoking and non-smoking parents: effects on physical fitness. Ann Sports Med1990;5:96–104.Google Scholar

Anderson O. Dodging the deadly cocktail. Running magazine.1989 Oct: 42, 43, and 64.Google Scholar

↵Gong H Jr, Krishnareddy S. How pollution and airborne allergens affect exercise. Physician and Sportsmedicine1995;23:35–42.Google Scholar

↵Stamford B. Exercise and air Pollution. Physician and Sportsmedicine1990;18:153–4.Google Scholar

↵Ekblom B, Huot R, Stein EM. Effect of changes in arterial oxygen content on circulation and physical perfomance. J Appl Physiol1975;39:71–5.PubMedWeb of ScienceGoogle Scholar

↵Pribyl CR, Racca J. Toxic gas exposures in ice arenas. Clin J Sports Med1996;6:232–6.PubMedWeb of ScienceGoogle Scholar

↵Coburn R, Forster RE, Kane PB. Consideration of the physiology and variables that determine the blood carboxyhaemoglobin concentration in man. J Clin Invest1965;44:1899–910.CrossRefPubMedWeb of ScienceGoogle Scholar

↵Colls J. Air pollution, an introduction. London: E & FN Spon, 1997.

↵Horner J. Carbon monoxide: the invisible killer. J R Soc Health1998;118:141–4.CrossRefPubMedGoogle Scholar

↵Blomberg A, Krishna MT, Helleday R, et al. Persistent airway inflammation but accomodated antioxidant and lung function responses after repeated daily exposure to nitrogen dioxide. Am J Respir Crit Care Med1999;159:536–43.CrossRefPubMedWeb of ScienceGoogle Scholar

↲Hazucha MJ. Relationship between ozone exposure and pulmonary function changes. J Appl Physiol1987;62:1671–80.CrossRefPubMedWeb of ScienceGoogle Scholar

↲Hazucha MJ, Bates DV, Bromberg PA. Mechanism of action of ozone on the human lung. J Appl Physiol1989;67:1535–41.PubMedWeb of ScienceGoogle Scholar

↲Hazucha MJ, Madden M, Pape G, et al. Effects of cyclo-oxygenase inhibition on ozone-induced respiratory inflammation and lung function changes. Eur J Appl Physiol1996;73:17–27.CrossRefGoogle Scholar

↲Folinsbee LJ. Air pollution: acute and chronic effects. Proceedings of Marathon Medicine 2000. London: The Royal Society of Medicine, 2001.

↲McKenzie DD, Stirling SF, Allen M. The effects of salbutamol on pulmonary function in cyclists exposed to ozone: a pilot study. Canadian Journal of Sport Sciences1987;12:46–8.Google Scholar

↲Raven PB. Questions and answers. Journal of Cardiac Rehabilitation1982;2:411–14.Google Scholar

↲Gong Jr H. Effects of ozone on exercise performance. J Sports Med1987;27:21–9.Google Scholar

↲Schelegle ES, Adams WC. Reduced exercise time in competitive simulations consequent to low level ozone exposure. Med Sci Sports Exerc1986;18:408–14.PubMedWeb of ScienceGoogle Scholar

↲Mihevic PM, Gliner JA, Horvarth SM. Perception of effort and respiratory sensitivity during exposure to ozone. Ergonomics1981;24:365–74.PubMedGoogle Scholar

↲Brunekreef B, Hoek G, Breugelmans O, et al. Respiratory effects of low-level photochemical air pollution in amateur cyclists. Am J Crit Care Med1994;150:962–6.CrossRefPubMedWeb of ScienceGoogle Scholar

↲McDonnell WF, Stewart PW, Andreoni S, et al. Prediction of Ozone-induced FEV1 changes. Effects of concentration, duration and ventilation. Am J Crit Care Med1997;156:715–22.PubMedWeb of ScienceGoogle Scholar

↲Stedman JR, Linehan E, King K. Quantification of the health effects of air pollution in the UK for the Review of the National Air Quality Strategy. A Report for The Department of the Environment, Transport and the Regions. Jan 1999.

↲Reichhardt T. Weighing the health risks of airborne particulates. Environ Sci Technol1995;29:360A–4A.CrossRefGoogle Scholar

↲COMEAP for the DoH. Non-biological particles and health. London: HMSO, 1995.

↲DoE, DoH and DoT. Health Effects of Particles. The Government's preliminary response to the reports of the Committee on the Medical Effects of Air Pollutants and the Expert Panel on Air Quality Standards. London: HMSO, 1995.

↲Watt M, Godden D, Cherrie J, et al. Individual exposure to particulate air pollution and its relevance to thresholds for health effetcs: a study of traffic wardens. Occup Environ Med1995;52:790–2.Abstract/FREE Full TextGoogle Scholar

↵van Wijnen JH, Verhoeff AP, Jans HWA, et al. The exposure of cyclists, car drivers and pedestrians to traffic-related air pollutants. Int Arch Occup Environ Healt.1995;67:187–93.Google Scholar

↵Bevan MAJ, Procter CJ, Baker-Rogers J, et al. Exposure to carbon monoxide, respirable suspended particulates and volotile organic compounds. Environ Sci Technol1991;25:788–91.CrossRefGoogle Scholar

↵Atkinson G, Maclaren D, Taylor C. Blood levels of British competitive cyclists. Ergonomics1994;37:43–8.PubMedGoogle Scholar

↵Grobler SR, Maresky LS, Kotze TJvW. Lead reduction of petrol and blood lead concentration of athletes. Arch Environ Health.1992;47:139–42.CrossRefPubMedWeb of ScienceGoogle Scholar

↵Pierson WE, Covert DS, Koenig JQ, et al. Implications of air pollution effects on athletic performance. Med Sci Sport Exerc1986;18:322–7.CrossRefPubMedWeb of ScienceGoogle Scholar

↵Linn WS, Venet TG, Shamoo DA, et al. Respiratory effects of sulfar dioxide in heavily exercising asthmatics. Am Rev Respir Dis1983;127:278–83.PubMedWeb of ScienceGoogle Scholar

↵Folinsbee LJ, Raven PB. Exercise and air pollution. J Sports Sci1984;2:57–75.Google Scholar

↵Wilber RL, Rundell KL, Szmedra L, et al. Incidence of exercise-induced bronchospasm in Olympic winter sport athletes. Med Sci Sports Exerc2000;32:732–7.CrossRefPubMedWeb of ScienceGoogle Scholar

↵Bernard N, Saintot M, Astre C, et al. Personal exposure to nitrogen dioxide pollution and effect on plasma antioxidants. Arch Environ Health1998;53:122–8.PubMedWeb of ScienceGoogle Scholar

Online ISSN: 1473-0480Print ISSN: 0306-3674

Evidence WR LTFC f

Evidence WR LTFC f

https://www.theguardian.com/environment/2016/mar/05/air-pollution-football-performance (accessed 20/8/23)

Arjen Robben playing for Bayern Munich in the German Bundesliga. Photograph: Michael Dalder/Reuters

This article is more than 7 years old

Is your football team playing badly? It may be air pollution

This article is more than 7 years old

Footballers' performance is affected by particles in the air, says German study

Jamie Doward

Sat 5 Mar 2016 22.00 GMT

Down the years, professional footballers have blamed a lacklustre performance on many things. Famous explanations have included the ball being too bouncy (Newcastle United); the pitch being too small (Tottenham Hotspur); and the team being forced to play in the wrong colour kit (Manchester United).

Now a group of health economists has discovered another reason that should send alarm bells ringing far beyond the world of sport. Andreas Lichter, Nico Pestel and Eric Sommer, researchers at the IZA economic institute in Bonn, Germany, will present a study at this month's Royal Economic Society's annual conference in Brighton which shows that air pollution is significantly affecting the performance of professional footballers. Their findings are based on analysing the form of players in Germany's Bundesliga between 1999 and 2011.

The three economists measured the total number of passes each player made in the matches in which they participated. "While the number of passes is not a measure of physical performance per se, it serves as our preferred productivity indicator since it is related to the speed of the game and, importantly, is highly relevant for a team's success by retaining ball possession and creating scoring opportunities," Lichter and his colleagues explained. "Moreover, passes provide a reliable measure, as passing is the essential nature of the game, which limits the role of chance."

The number of passes was then mapped against hourly air pollution data collected outside each stadium by the German Federal Environment Agency.

The economists found that, at kick-off on any given match day, the mean concentration of pollution, the “particulate matter”, was 23.8 micrograms per cubic metre. In almost half of the matches covered (44%), the level ranged between 20 and 50 micrograms per cubic metre, the latter figure being the European Union regulation threshold for particulate pollution. This threshold was exceeded in 7% of the matches.

The economists found that player performance was impeded by pollution even at levels well below these health limits. And at high levels – above the EU threshold – there was a significantly noticeable decline equivalent in performance, by as much as 16%.

Some players were more affected by air pollution than others. The researchers write: “We find that negative effects of pollution on short-run productivity increase with the individuals’ age and are largest for players aged above 30. Moreover, midfielders’ and defenders’ productivity is particularly affected by pollution, players who are more attached to the game and exert a larger number of passes.”

They found that the shorter the gap between games, the more pronounced were the effects of air pollution on performance. Intriguingly, there is some evidence that the players adapted to higher levels of pollution. “Our analysis also suggests that players tend to marginally adjust their style of play, given that the ratio of long over short passes slightly increases with the concentration of particulate matter,” they note.

The findings are likely to be studied far beyond the world of professional football. And the academics want more work to be done to assess what impact pollution has on other professions’ “physical and cognitive productivity” and to broaden knowledge on the benefits of environmental regulation.

The European Environment Agency says the financial impact of air pollution on Europe’s population could be as high as €200bn (£154bn). About 40,000 people are estimated to die prematurely every year in the UK because of poor air quality. In April the Supreme Court ruled that an immediate plan was needed after the UK breached EU limits for nitrogen dioxide. Last week the government was threatened with legal action if it does not take steps to introduce the plan urgently.