Air pollution is a global problem and is believed to kill more people worldwide than AIDS, malaria, breast cancer or tuberculosis. Even though air pollution sometimes results from forest fires or desert sand storms, it is largely associated with urban areas and large cities. Since the population living in urban areas has increased rapidly over the last 2 decades, the health consequences of air pollution are expected to create an increasingly larger illness burden in years to come. Today, around 50% of the global population lives in urban areas, but in the developed world this figure is approaching 80%. Airborne particulate matter (PM) is especially detrimental to health and has been estimated to cause between 3 to 6 million deaths per year alone, primarily via cardio-respiratory diseases.

For many obvious reasons, large urban centres are almost always the location for major sports events such as the Olympic/Paralympic Games, World Championships, World Cups, Commonwealth Games etc. Since the Olympic Games in Los Angeles in 1984, the concern about air pollution being a health hazard for athletes has been an issue for several major sports events. It was further compounded by endeavours to bring major events to developing countries with lower standards for environmental protection. The 2008 Beijing Games epitomised this problem. The organisers did a remarkable job in improving the air quality in the megacity immediately before and during the event, but still it was favourable weather conditions and wind directions beyond the control of the organisers that played a major part in limiting the harmful health effects of air pollution. Beijing is certainly not the only host city that has posed potential health hazards to competing athletes over the last 4 decades, but the attention it received illustrates the dilemma between protecting the health of athletes and finding venue cities capable and willing to host such large events.

This article will not argue this matter further, but instead briefly answers a few purposeful questions to assist organisations’ decision-makers in their task with facts and figures.

WHERE IS AIR POLLUTION MOST PROMINENT?

Regardless of its geographical origin, air pollution moves freely around and respects neither city nor national borders. Most often it is a mix of several pollutants that come from multiple sources. Local topography (mountains, deserts, sea, etc.), climate (temperature and humidity) and weather conditions (sun, rain, wind) may have a significant impact on the magnitude of air pollution in a geographical area. However, it
is the amount of particles and gases emitted into the air from different sources that constitutes the root cause of air pollution. Consequently, air quality is most often compromised in heavily industrialised areas with large populations.

The world map with Air Quality Indices (AQIs) for major cities (Figure 1) shows this trend, although, when checking for specific urban areas, you will find surprisingly large local variations. Thus, big cities with favourable topography, climate and weather conditions, may be better off than smaller cities surrounded by mountains or deserts with high temperature and humidity. In cooler climate zones, the winter season with increased fossil fuel burning for heating, may cause a drastic accumulation of air pollution on days with no wind and stagnant cold air.

While Figure 1 shows a map of the world with AQIs for the major cities at a randomly picked date, on the website www.aqicn.org/map/world, you can access the local AQI in your area and get more information on daily and hourly changes. Air quality/pollution changes with the ‘diurnal rhythm’ of the sources emitting the pollutants, for example, pollution from automobiles. Thus, some hours of a 24-hour period are better or worse than others and should direct the time and location in which you choose to exercise. Generally, early mornings on a hillside away from the traffic are better than evenings ‘down’ in a city along major traffic routes. It is wise to use the AQI map for daily updates on local air quality. A guide to AQI can be found at www3.epa.gov/airnow/aqi_brochure_02_14.pdf.

WHAT TYPES OF POLLUTANTS ARE MOST HARMFUL?

According to a recently published article in *Nature*, these are the main sources of air pollution, ranked by their contribution to air pollution from a global perspective:

1. Domestic (home) heating and cooking from open woodstoves and diesel generators.
2. Agriculture, mainly through ammonia gases reacting with other gasses and forming PM.
3. Fossil-fuelled power plants.
4. Industrial production and activity.
5. Land-based transportation.
6. Wildfires and burning of forests.
7. Desert sand storms and other natural particles.

The order of importance to air pollution and consequently ill health will change from one continent or country to another, depending on the predominance of a specific pollution source in a region. Industry and transportation may be the dominating sources of pollution in metropolitan areas and megacities, while open fires and farming may be the main sources in rural areas.

Furthermore, air pollution is not one entity, but a host of different gases and PM. It is beyond the scope of this article to give a detailed description of all contributors to air pollution. This can be found in several of the publications included in the ‘further reading’ for this paper. Thus, only a list of the most common pollutants associated with health hazards and illnesses is given in Box 1. In addition to the individual effects each of these pollutants has on our health, there are synergy effects between single sources of pollutants. That means, the co-existence of two pollutants may increase the negative effect that each of them might have individually.

High temperatures and humidity are also known to potentiate the detrimental effect of several pollutants. It is well documented that temperatures above 30° Celsius on days with increased ozone levels (above 100 ppb) will reduce exercise capacity and performance if lasting longer than 60 to 90 minutes. Oxidative stress, bronchial hyperactivity and...
airway inflammation are responsible for this impaired exercise capacity.

Since PM is the dominating air pollutant that causes greatest harm to health in most parts of the world, a brief description of this pollutant is warranted. Airborne PM is categorised by aerodynamic diameter and includes the categories of coarse, fine and ultrafine particles. Particles larger than 10 µm are not considered harmful to airways since they are primarily filtered in the nasopharyngeal region. Smaller particles which represent various health risks are categorised as coarse, fine or ultrafine particles. Coarse particles (PM10) include those between 2.5 and 10 µm in diameter. Fine particles (PM2.5) are smaller than 2.5 µm in diameter. Ultrafine particles of less than 0.1 µm can also be identified and are believed to have the most deleterious effect on both health and exercise capacity.

Sources of PM include combustion engine automobiles and aeroplanes, industrial facilities and electric power plants, wild fires and biomass burning and fossil fuels used in homes and factories for heating.

PM is associated with respiratory conditions such as asthma, bronchitis, chronic obstructive pulmonary disease and cardiovascular conditions such as arteriosclerosis, myocardial infarction, stroke and hypertension. Potential consequences of inhaling PMs during exercise include decreased lung function, exacerbations of asthma, exercise-induced bronchoconstriction, decreased diffusion capacity and decreased performance.

FOR WHOM IS AIR POLLUTION A PROBLEM AND WHAT ARE THE GUIDELINES AND LIMITS FOR AIR QUALITY?

As a general rule, both environmental (extrinsic) and host (intrinsic) factors interact and determine the individual response to an environmental challenge. Box 2 lists the most common environmental and host factors that interplay in the reaction to an air pollutant.

For most environmental agents to trigger a reaction in a host/human, a minimum concentration (threshold) is needed. Moreover, this minimum concentration has to be present over a certain time period before pathophysiological changes in human tissues and organs are detected. Additionally, temperature and humidity can modify (most often potentiate) the effect of exposure to pollutants, irritants and allergens.

From the host perspective, if a pollutant or irritant is present in a sufficiently high concentration and over a sufficiently long time period, any individual will react to such exposure. In other words, changes in human tissues and organs can be observed in anyone if a pollutant is present above certain doses over time. However, several constitutional factors and pre-existing conditions such as asthma, allergy and atopy will further determine the outcome of such exposure to a specific pollutant. Typically, individuals with certain constitutional factors and conditions will react to a lower dose of a pollutant than healthy people. They will also manifest a stronger pathological response when exposed to the same dose compared to ‘normal’ individuals. Thus, there is a large variability from one individual to another in reacting to different pollutants and irritants.

Furthermore, when exposed to air pollutants and irritants, the activity level of an individual will influence the tissue reaction in lungs and other organs. Unfortunately, physical activity above a certain intensity appears to increase the deleterious effects of air pollutants, because exercise-increased ventilation leads to greater deposition of pollutants in larger areas of the respiratory tract.

### Box 1

**Table 1**

<table>
<thead>
<tr>
<th>AQI</th>
<th>Air pollution level</th>
<th>Health implications.</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-50</td>
<td>Good</td>
<td>Air quality is considered satisfactory, and air pollution poses little or no risk.</td>
</tr>
<tr>
<td>51-100</td>
<td>Moderate</td>
<td>Air quality is acceptable; however, for some pollutants there may be a moderate health concern for a very small number of people who are unusually sensitive to air pollution. Members of sensitive groups may experience health effects. The general public is not likely to be affected.</td>
</tr>
<tr>
<td>101-150</td>
<td>Unhealthy for sensitive groups</td>
<td>Everyone may begin to experience health effects; members of sensitive groups may experience more serious health effects.</td>
</tr>
<tr>
<td>151-200</td>
<td>Unhealthy</td>
<td>Health warnings of emergency conditions. The entire population is more likely to be affected.</td>
</tr>
<tr>
<td>201-300</td>
<td>Very unhealthy</td>
<td>Health alert: everyone may experience more serious health effects.</td>
</tr>
<tr>
<td>300+</td>
<td>Hazardous</td>
<td></td>
</tr>
</tbody>
</table>

Table 1: World Health Organisation guidelines on air quality index and health implications.
areas of the lung compared to resting ventilation. This is discussed further in the next section.

WHY ARE ATHLETES MORE SUSCEPTIBLE TO THE HEALTH HAZARDS OF AIR POLLUTION THAN THE NORMAL POPULATION?
Higher breathing volumes increase the overall exposure to air pollutants and cause more air to bypass the protective filtration in the nose, resulting in deposition of pollutants in more peripheral and larger areas of the lungs. Furthermore, the mucociliary resistance in the airways may be inhibited by strenuous exercise. Additionally, airway epithelium damaged by the mechanical stress of high ventilation may allow for particle infiltration into the circulatory system and thus increase the systemic ill-health effect of PM and air pollutants in general. Nevertheless, the many positive health effects of exercise by far outweigh the negative consequences of air pollution when being physically active. Finding a local exercise environment that gives the least exposure to air pollutants is the key to reaping the benefits of exercise while simultaneously minimising the health hazards of these pollutants.

Athletes with asthma, bronchial hyper-reactivity and allergies must be monitored closely and optimally treated according to international standards, when exposed to air pollution. Furthermore, they must be aware of the aggravating effects of extreme temperatures (warm and cold) as well as high humidity levels.

WHAT ARE THE CONSEQUENCES OF AIR POLLUTANTS ON EXERCISE AND HEALTH?
The sequence of physiological events that takes place during exercise may be adversely influenced by the effects of air pollution on several organs and systems. This involves airway narrowing, reduced pulmonary gas diffusion and arterial oxygenation, cardiac ischaemia, altered autonomic innervation, vasoconstriction and increased blood viscosity. The degree to which these alterations will manifest themselves during exercise is dependent on many extrinsic and intrinsic factors, including pre-existing cardiorespiratory illnesses. Although there are gaps in our knowledge on how much various pollutants affect exercise capacity and at what concentrations, there is sufficient scientific evidence to claim that, collectively, such physiological aberrations will result in a decreased capacity to exercise and perform.

Two recent reviews offer excellent summaries of the scientific documentation on how air pollution is associated with reduced exercise capacity and ill health. Table 2 summarises the present knowledge on alterations in organs and systems from the most studied air pollutants, as well as their impact on exercise.

The effects of air pollution on health will also depend on the type and magnitude of air pollution, typically manifesting itself over a longer period of exposure, although there may also be acute effects on health from short-term exposure to certain air pollutants such as carbon monoxide. ‘Coal miner’s lung’ was one of the first recognised illnesses caused by exposure to carbon particle air pollution. Since then, many cardiorespiratory and systemic illnesses have been linked to air pollution. With increasing understanding of how several pollutants affect human physiology and specific organ functions over the last decades, air pollution has been implicated in the development of many chronic diseases.
with premature death as an ultimate consequence.

As mentioned at the start of this paper, between 3 and 6 million deaths per year can be ascribed to air pollution (depending on the inclusion/exclusion of deaths related to open-fire home cooking/heating). This high mortality is linked to a substantial burden of illnesses and reduced quality of life that precedes death. Consequently, the rapid rise in air pollution in many areas of the world represents an increasing threat to the health of millions of people.

WHAT PRECAUTIONS AND MITIGATING ACTIONS CAN BE TAKEN?

Are there any remedies to air pollution in areas that are already substantially affected other than the obvious, namely, to eradicate the source? Are there any mitigating actions for those individuals who have no choice but to train or compete in such areas? The answer is definitely 'yes', there are a number of actions which can be taken, but it requires a joint effort of governing bodies, sports organisations, event organisers and the athlete or team. On the one hand, field studies show substantial improvement in air quality by just moving a competition venue 50 to 100 metres further away from a road with heavy traffic. Consequently urban planners and venue organisers must keep this in mind when making decisions on locations for arenas and events. On the other hand, sports teams, athletes and exercisers can minimise the deleterious effects of air pollution by making smart choices about when, where and how to train in pollution-exposed environments.

Below are some precautions and mitigating actions that sports venue planners/event organisers, as well as sports teams and individual athletes/exercisers should consider to minimise the undesirable effects of exercising in areas with poor air quality. The list is by no means exhaustive, but presents the more feasible actions.

Planners and organisers:
1. Perform detailed measurements of air quality before deciding on the location of a sport facility or event site.

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**Table 2**

<table>
<thead>
<tr>
<th>Air pollutant</th>
<th>WHO air quality guideline</th>
<th>Affected system/organ</th>
<th>Key physiological changes*</th>
<th>Acute effect on exercise*</th>
<th>Long term effect/illness*</th>
</tr>
</thead>
<tbody>
<tr>
<td>PM 2.5</td>
<td>25 microgram/m³ over 24h</td>
<td>Respiratory tract and lungs</td>
<td>Oxidative stress</td>
<td>Increased airway resistance</td>
<td>Asthma</td>
</tr>
<tr>
<td>PM 10</td>
<td>50 microgram/m³ over 24h</td>
<td>Cardiovascular</td>
<td>Inflammation</td>
<td>Reduced maximal oxygen uptake</td>
<td>Bronchitis</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Oxidative stress</td>
<td>Impaired aerobic work capacity</td>
<td>COPD</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Platelet aggregation</td>
<td></td>
<td>Atherosclerosis</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Inflammation</td>
<td></td>
<td>Stroke</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Vasoconstriction</td>
<td></td>
<td>Angina/myocardial infarction</td>
</tr>
<tr>
<td>Ozone</td>
<td>50 ppb over 8h period</td>
<td>Respiratory tract and lungs</td>
<td>Oxidative stress</td>
<td>Reduced maximal oxygen uptake</td>
<td>Hypertension</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Inflammation</td>
<td>Impaired aerobic work capacity</td>
<td>Arrhythmia</td>
</tr>
<tr>
<td>Carbon monoxide</td>
<td>9 ppb over 8h period</td>
<td>Respiratory tract and lungs</td>
<td>Hypoxia</td>
<td>Increased ventilation</td>
<td>Bronchial hyper-reactivity</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Cell death</td>
<td>Increased sub-maximal heart rate</td>
<td>Asthma</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Reduced maximal oxygen uptake</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Impaired aerobic work capacity</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Impaired cognition</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Brain damage</td>
<td></td>
</tr>
</tbody>
</table>

Table 2: Effects of air pollutants on exercise and health. *effects occurring with exceeding of the World Health Organisation threshold. COPD=chronic obstructive pulmonary disease.
finding a local exercise environment that gives the least exposure to air pollutants is the key to reaping the benefits of exercise while simultaneously minimising the health hazards of these pollutants

2. Identify the major air pollution sources in the area considered for sports and exercise activities.
3. Take appropriate actions to minimise the local air pollution if an event is taking place in a polluted area.
4. Choose practice fields and competition venues that are as far removed from a pollution source as possible. As little as a 50 to 100 metre change in location could make a significant difference.
5. Provide updated measurements of the air quality to local and visiting athletes and inform athletes and teams on how to minimise the risk of impaired exercise capacity and ill health.
6. Avoid all use of fossil-fuelled vehicles and machinery inside a sports arena.

Teams and athletes
1. Avoid exercising along or nearby roads with heavy traffic or in areas with industrial pollution.
2. Exercise in the morning before rush hours, if possible.
3. Monitor the local AQI, follow recommendations from local health authorities and avoid high-intensity or long-duration exercise on days with poor air quality.
4. Wear a face mask on days with poor air quality.
5. Athletes with asthma, allergies or other airway illnesses should be diligent about keeping to their treatment plan and adjust their medication according to changes in air quality and illness symptoms.
6. If experiencing symptoms of respiratory infections, be extra cautious about minimising exposure to air pollutants.
7. Antioxidant supplementation in moderate amounts and/or small doses of inhaled corticoids may be considered, if otherwise healthy athletes are experiencing airway symptoms due to a sudden increase in air pollution.

SUMMARY
Indisputably, the well-documented health benefits of exercise by far outweigh the potential negative effects of exercising in areas with impaired air quality. Nevertheless, on an individual basis, it is important to be aware of the potential detrimental effects of air pollution and take appropriate actions to minimise the degree of exposure. There is still a considerable lack of evidence-based knowledge on the cause-effect and dose-response relationships between several air pollutants and health, as well as exercise capacity. However, what we already know is sufficient to raise alarm bells and take action.

This brief review is intended to assist both individual athletes and sports event organisers in making better and more informed decisions on training and competitions in polluted environments. Sports organisations like the International Olympic Committee and International Sports Federations have adapted the slogan ‘Protecting the health of our athletes’, claiming it to be on top of their priority list. However, when major sport events are awarded to metropolitan areas with poor air quality, this priority is not so obvious, because it challenges many athletes’ health and performance, particularly those with airway diseases like asthma and allergies. How far are these sports organisations willing to go in placing specific demands on air quality before the event is awarded to a city, and more importantly, introducing specific air quality indices before the event is hosted?

Further reading

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