Elite Athletes, Air Quality and the AQHI

Health Canada

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Communication Solutions Inc.
www.solutiongroup.ca

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Introduction

Since its introduction in 2003 the AQHI has been used by Canadians to help avoid exposure to the health risks associated with poor air pollution. Throughout Canada there has been a significant investment in increasing awareness of the AQHI among identified risk populations as well as the general public.

Elite athletes have been identified as an at-risk population because of the intensity and duration of exposure to outdoor air quality. Elite athletes are motivated by any training factors that impact peak performance and have generally low awareness of the impact that air quality can have on both health and performance.

Individuals tend to rely on sensory perception to evaluate air quality when, in fact, the pollutants that present the greatest harm to human health are difficult to see or smell. Athletes will not be able to limit exposure if they rely on sensory perception alone even if they understand the potential health impacts of poor air quality.

Canada's Air Quality Health Index provides the world's first air quality index that measures the combined health risk of pollutants. Currently, the AQHI is reported on an hourly basis (based on a three hour trailing average) and AQHI maximum is forecasted twice daily from a network of stationary monitoring stations. Although the AQHI offers Canadians real-time reporting of the health risk associated with the current air quality as well as a 36 hour forecast projection , it may require more frequent reporting and forecasting to meet the needs of the elite athlete whose training or competition schedule may include regions without monitors, or may fall between AQHI updates.

This report examines the awareness, need and potential use of the AQHI in helping reduce health risk and exposure in the elite athlete population, and reviews current research quantifying the performance impact of training and competing in poor air quality.

In addition, the ethical and legal obligations to provide a safe training and competition environment are considered as well as the opportunity for Canada to create a point of difference in the sport event hosting marketplace based on good air quality and excellence in air quality sensing and reporting.

Convergence and Opportunity

A unique convergence of science, technology, motivation and interest provide an opportunity to showcase the AQHI to a broad Canadian and international audience, and increase awareness within the elite athlete community.

Short and long term health impacts from air pollution are well documented and a great deal of work is being done to quantify the performance impacts of poor air quality. International attention on urban air quality during recent, and upcoming, Olympic Games has increased awareness even more. Elite athletes are beginning to understand that air quality can be an important training and competitive consideration. However, as found in work with other at-risk populations, this awareness and uptake will be increased if athletes use the AQHI to limit exposure.

At the same time, the Canadian scientific community is advancing mobile sensing and reporting technology. These developments parallel the work being done internationally to build personal sensing and reporting devices.

Opportunities to align the AQHI with major international sporting events are also available, with both the 2015 Pan Am Games and the 2015 Women's

World Cup being possible event targets to showcase AQHI technology.

PART 1: ATHLETES AND AIR QUALITY

For the purposes of this study, elite athletes are defined as those who compete at a national or international level. Elite athletes are motivated by the achievement of peak performance and any training or competitive advantage will gain their attention.

Major national and international sporting events will always be hosted in major urban centres due to the available infrastructure and populations. Environmental factors, including air quality, will be increasingly important as the world's competitive venues become more and more polluted and as the frequency of asthma diagnosis increases.

Understanding the Elite Athlete

The needs and motivations of the elite athlete are unlike those of any other at-risk population. The athlete is focused on achieving peak performance and is less concerned about long-term health impacts of a training regime.

Athletes must consider a myriad of environmental, nutrition and training factors in order to peak at a targeted competition. Historically, unless challenged by a previous respiratory diagnosis such as asthma, athletes rarely considered air quality an important training factor. Although integration with the National Coaching certification program is now underway, even coaches have been traditionally unaware of the health impacts of training or competing in regions with poor air quality.

Athletes are motivated to maintain health in order to optimize training and competitive performance. Often the difference between a first place and fourth place finish is measured in 1 or 2 percentiles. Each athlete is looking to gain even a slight competitive advantage and if management of exposure to poor air quality can be linked to even minute changes in performance then athlete motivation to manage this training factor will be enhanced.

More recently, athletes awareness of venues with extremely poor air quality is increasing. Some may even opt to avoid high profile competitions in those environments. Informed athletes are concerned that extremely poor air quality may impact performance and their world standing in that event. Games organizers are aware that poor air quality has the potential to prevent record-breaking performances or even result in an athlete's withdrawal from competition.

Awareness of Air Quality

As stated, awareness of performance and health impacts of poor air quality is generally low among elite athletes. However, athletes with pre-existing lung or cardiac conditions, as well as those who have experienced the adverse effects of air pollution – are more likely to monitor air quality and take steps to reduce exposure.

Increased Awareness through International Competition

Media coverage of air quality in the Beijing Olympic Games and the Commonwealth Games in Delhi has raised awareness of the possible performance and health impacts of poor air quality. In both these competitions, international media were prompted by the visibly degraded air quality in these cities. Unfortunately air quality reporting was not established enough in either location to help athletes make informed decisions to reduce exposure.

Knowing that it was neither possible nor desirable to acclimatize athletes to air pollution, Randy Wilber, Physiologist with the US Olympic Committee, made recommendations for helping athletes perform optimally in Beijing. “The best strategy is the alternative training site. Stay away from it (air pollution in the city); do not expose yourself to it” (Wilber R. , 2008).

Athletes in Beijing were made aware of the possible impacts of air pollution on performance and some even withdrew from their events knowing that a peak performance was not possible. Most notable was Haile Gebrselassie, who held the world record for the marathon leading up to the Beijing Olympic Games. The projected decrease in Gebrselassie's lung function in the highly polluted environment was 1-2 percent – a difference great enough to risk his world standing. Gebrselassie withdrew from the Olympic event and chose not to risk his world record – or the long term consequences of exposure - stating that "the pollution in China is a threat to my health" (Bernhardt, 2008).

Gebrselassie's withdrawal increased international attention on the possible performance impacts of poor air quality. His anticipated performance impact parallels the findings of other researchers. Marr and Ely found a predictable 1.4% decrease in the performance of female marathon runners for every 10-microg x m^{-3} increase in PM_{10} (Marr & Ely, 2010).

Air quality will undoubtedly receive significant attention at the London summer Olympic Games where pollutant loads regularly exceed European Union guidelines. Already respiratory scientists are warning that Olympic athletes could suffer impaired performance times and become ill as a result of London's unacceptably high levels of air pollution, exacerbated by frequent summer inversions. Frank Kelly, Professor of Environmental Health, King's College London, notes "a few athletes may not attain the performances they hoped to and they might spend a few days feeling unwell. From an athletic point of view, they will not be at the best of their ability" (Sombach, 2012).

Air quality at the London Olympics threatens to overshadow any other issue at the event. Games organizers have conceded that a dramatic traffic reduction will be required, and yet even those efforts may not be enough to provide a safe competitive environment. According to the Olympic Delivery Authority's Strategic Environmental Assessment (SEA), published in April 2012, the expected increases in traffic…will lead to further breaches of European legal limits in areas that already suffer from poor air quality. Even a 30% reduction in normal traffic during the period of the Olympics may not be enough to bring emissions below the legal limit (Vidal & Gibson, 2011).

WHO IS AT RISK

All athletes are susceptible to the performance or health impacts of exercising in poor air quality. As described previously, athletes are at increased risk of inhaling pollutants because of their increased minute ventilation, more mouth breathing and increased air flow velocity which drives pollutants deeper into the lungs.

Some athletes have a heightened sensitivity to poor air quality due to pre-existing lung or cardiac conditions.

Elite Athletes

No matter what their sport, most athletes participate in some form of outdoor training or endurance activity that exposes them to air pollution. Some however, will have an enhanced exposure to poor air quality because of their competition venue or season.

Athletes commonly train near urban centres where air quality is poorer, but even those training in rural locations may encounter seasonal spikes in poor air quality. Swimmers are the most highly affected summer athlete group because of the chemicals required to maintain water quality and the closed environment. In winter, outdoor athletes are challenged by cold, dry environments, while those training in arenas are exposed to combustion exhaust from ice cleaning equipment within a closed air system.

High intensity and endurance athletes are at particular risk because of long exposure times and the peak cardiovascular and respiratory performance levels.

Women appear to be more affected than men by poor air quality possibly due to smaller airways, lungs and respiratory systems. (McKenzie). Marr confirmed these findings, revealing a greater vulnerability to PM in female marathon runners when compared to males (Marr & Ely, 2010).

High Exposure Sports

Piturro correlated the following sports with the highest potential exposure to poor indoor or outdoor air quality (Piturro, 2008).

- Summer: triathlon, running, cycling, soccer, rowing, tennis, swimming
- Winter: cross-country skiing, downhill skiing, hockey, figure skating and speed skating
- Paralympics: see discussion below

Athletes with Asthma

The incidence of asthma within the general population is on the rise throughout the developed world and an even more dramatic increase has been documented in athletes. Asthma is now twice as prevalent in elite athletes (11-50%) as the general population (4-20%) (Unal, Sahinkaya, Namarash, Akkaya, & Kayserilioglu, 2004).

Asthma increases sensitivity to air pollution, easily triggering inflammatory response associated with the condition. In winter, the dehydration of airways is exacerbated causing a mediator release that results in airway narrowing - the same process occurs with exposure to air pollution.

McKenzie proposes that intense exercise and environmental conditions contribute to the development of asthma in highly trained athletes (McKenzie & Boulet, 2008). Poor air quality is thought to exacerbate asthma and may decrease peak performance.

Winter athletes are twice as affected as summer athletes, with a record 67.8% at the 2010 Winter Olympics. Cross-country skiers have the highest rate of exercise induced bronchospasm with 26% of women and 18% of men having a confirmed diagnosis. Asthma has increased from 3.7% to 22.8% in elite summer athletes (Wilber, Rundell, Szmedra, Jenkinson, & Drake, 2000).

About one of every five athletes who participated in the 1996 Summer Olympic Games in Atlanta had a history of asthma, had symptoms that suggested asthma, or took asthma medications. In the 1998 Winter Games, athletes who participated in Nordic-combined, cross-country, and short track events had the highest prevalence of asthma or had taken an asthma medication in the past (60.7%) in contrast with only one (2.8%) of the 36 athletes who participated in bobsled, biathlon, luge, and ski jumping. Eighteen (24%) of 75 athletes who participated in alpine, long track, figure skating, snowboarding, and curling had a previous diagnosis of asthma or recorded use of an asthma medication. This research suggests that the exercise environment is a critical trigger for asthma (Wilber, Rundell, Szmedra, Jenkinson, & Drake, 2000).

Paralympic Athletes

McKenzie noted a lack of research into the relationship between air quality and exercise in Paralympic athletes. Altered breathing mechanics, poor sympathetic control and impaired cough reflexes may contribute to increased cardiac and respiratory risk in wheelchair athletes, especially those with spinal cord injuries (McKenzie & Boulet, 2008). The additional challenges presented by air pollution could limit performance and result in significant health consequences.

The autonomic control of heart rate and blood pressure is often impaired in athletes with high spinal cord lesions – and so the cardiovascular response to physical activity can fail to meet the demand (Mills & Krassioukov, 2011). The additional documented cardiovascular impacts of poor air quality may further decrease peak performance and increase health risk (Theisen, 2012).

Funding for Paralympic athlete assessment and support is often less than for able-bodied athletes. Even competition venues may be less safe for Paralympic athletes. For example, in Beijing efforts to reduce air pollution resulted in a 30% decrease in PM10 during the 2008 Olympic Games when international attention was focused on the poor air quality in the region (van Bree, 2009). In the weeks following the Games, local traffic and factories gradually returned to normal operations in the lead-up to the Paralympic Games. Air pollution levels reportedly returned to near pre-event levels and athletes with additional risk factors were seeking peak performances in a high risk environment (Esau, Fletcher, & MacIntosh, 2008).

PART 2: HEALTH AND PERFORMANCE

Health risks associated with poor air quality are well documented and a great deal of work is underway to quantify and document performance impacts.

The most recent research suggests that although everyone is impacted by poor air quality to some degree; particular populations are more sensitive to the health effects of this exposure. One of those populations is the high performance elite athlete.

Health Impacts of Air Pollution

Both short and long term, respiratory and cardiac impacts have been linked to air pollution and exercise (Mroszczyk-McDonald, ND), and yet elite athletes are rarely aware of the health risk associated with training or competing in an environment with poor air quality.

The health risk from air pollution is determined by the pollutant load, the time and location of physical activity, the duration and intensity of exercise as well as individual sensitivity. Short and long term health impacts as well as peak performance impacts have been documented. Dr Dave Stieb describes the relationship between dose and exposure (Stieb, 2011):

Dose =
Concentration x Intake Rate x Exposure Duration

The metabolic demands of exercise increase minute ventilation and therefore the rate of inhalation of pollutants. Athletes are at increased risk due to the increased frequency of ventilation, the depth of inhalation as well as the by-passing of many of the body's natural defenses due to oral breathing.

Respiratory Impacts

Endurance athletes' sensitivities to air pollution are increased for a variety of reasons including increased ventilation rates, increased oral breathing, and long exposure times as well as athletes' highly efficient respiratory system.

Increased ventilation rate may result in a significant increase in inhaled pollutants, including $PM_{2.5}$ (fine) and $PM_{0.1}$ (ultrafine) particles as these minute contaminants are drawn deeply into the lungs to the site of gas exchange. Vehicle exhaust is the primary source of these pollutants in an urban setting.

Potential respiratory consequence of inhaling pollutants during exercise include decreased lung function, exacerbation of an existing lung condition (asthma / exercise induced bronchospasm) and pulmonary hypertension and decreased performance.

Athletes typically take in 10-20x as much air with each breath in comparison to a sedentary population, inhaling a corresponding amount of pollutants. A marathon runner is estimated to inhale the equivalent of 2 days of air during an event (Reynolds, 2012).

Mackenzie observed periods of hypoxemia in laboratory studies of healthy athletes. During peak performance an athlete's airways, chest wall and gas exchange mechanisms cannot keep up with the oxygen demand of cardiac and skeletal muscles. Consequently up to 50% of endurance athletes experience periods of hypoxemia during peak performance (McKenzie & Boulet, 2008). This effect is amplified if the athlete is also experiencing the adverse effects of poor air quality.

Cardiovascular Impacts

Recent research suggests that the cardiovascular effects of air pollution may outweigh respiratory concerns.

The adverse effects of air pollution on cardiovascular health have been established in a series of major research studies. Even brief exposures to air pollution have been associated with increases in cardiovascular-related morbidity and deaths from myocardial ischemia, arrhythmia, and heart failure (Mills, et al., 2009)

The cardiovascular changes related to exercise in highly polluted environments can result in an arterial plaque or blockage and combine to create the perfect conditions for cardiac events (Reynolds, Air pollution holds risks for athletes who exercise outdoors , 2007).

When an athlete inhales pollutants deep into the lungs an inflammatory response occurs, which may lead to impaired gas exchange between the alveoli and pulmonary blood vessels. Mills et al examined the impact of ultrafine particular matter which migrated from the lung into the bloodstream after being inhaled deeply into the lungs (Mills, et al., 2009). In the study, 30 healthy volunteers rode exercise bikes for 30 minutes while inhaling diesel exhaust at levels close to those along a city highway during rush hour. A post-exercise examination of the subjects revealed abnormally dilated blood vessels. Peripheral vessel dilation meant that blood could not flow easily to the muscles and pulmonary vessel dilation impaired gas exchange. A decrease in levels of the clot-dissolving protein tPA in the same subjects.

Traffic pollution has been shown to increase risk for cardiovascular disease due to the increased atherosclerosis that results from inhaled fine particles migrating into the pulmonary vessels (Sharman, Cockcroft, & Coombes, 2004; 97).

In addition, research by Weichenthal et al suggests that short term exposures to traffic pollution may impact autonomic modulation of the heart in the hours immediately after exercise. Weichenthal documented a decreased heart rate variability which, in other studies, has been correlated to an increased risk of cardiovascular morbidity / mortality (Weichenthal, Kulka, Dubeau, Martin, Wang, & Dales, 2011). A second study by Shaffer et al showed increased frequency of premature ventricular contraction in healthy individuals following $PM_{2.5}$ exposure during exercise (Shaffer, Rodriguez-Colon, Yanosky, Bixler, Casio, & Liao, 2011).

Significant increases in pulmonary artery pressure have also been documented after exercise in high pollution environments. The change in arterial pressure changes was correlated to decreased exercise performance of up to 24.4% (Brunekreef, Hoek, G, & Leentvaar, 1994).

Pollutants of Concern

Research studies lead to the conclusion that air pollution adversely affects athletic performance during training and competition. The inhaled amount of air pollutants during exercise is much higher during exercise due to the marked increase in respiratory rate as well as the nasal and oral breathing.

Although there are a myriad of air pollutants, the greatest overall health impact is from fine particulate and ozone. Particulate air pollution refers to a combination of fine solids that are formed in the atmosphere. Fine and ultrafine particulate matter is easily inhaled deep into the lungs where it can create an inflammatory response in the respiratory system or cross into the bloodstream (Mroszczyk-McDonald, ND).

Vehicles are the primary source of air pollution in the urban environment and the freshly mixed pollutants found in vehicle exhaust are the most harmful to health. Acute exposure to freshly-mixed vehicle exhaust during exercise has been shown to cause decreases in lung function in both healthy and asthmatic subjects (Rundell, 2012). Whereas, chronic exposure to the same exhaust during exercise may result in decreased lung function and may lead to cardiovascular dysfunction.

Freshly-mixed emissions from any combustion engine, including vehicles and ice-resurfacing equipment, have been shown to be more highly toxic than any individual pollutant (ibid).

Recent work by Stieb et al correlated emergency room visits to exposure to individual pollutants. Results show that ozone exposure is most closely linked to respiratory distress, $PM_{2.5}$ exacerbates asthmatics and increased CO / NO_2 increased ER cardiac visits (Stieb, Szyszkowicz, Rowe, & Leech, 2009).

In the elite athlete population, CO exposure has been shown to impair athletic performance (Carlisle & Sharp, 2001) and acute PM exposure decreases performance in athletes with and without asthma (McKenzie & Boulet, 2008). Although environmental concentrations of SO_2 are typically low, athletes often have a high sensitivity to SO_2 even after 5 minutes of exercise (Carlisle & Sharp, 2001).

Physiological Impacts of Single Pollutants

PARTICULATE MATTER: Particulate matter is measured according to the size of the pollutant particles. PM toxicity is related to the size, volume and charge of these particles. Smaller particles, known as fine and ultrafine PM, have a greater health impact due to their ability to bypass the body's mechanical filters and their ability to penetrate more deeply into the lungs to the site of gas exchange. Ultrafine particles concentrations are high in freshly mixed exhaust but dissipate quickly over time. PM_{10} consists of more coarse particles and, although they irritate the respiratory system, they are often filtered through respiratory defense systems and have less health impact.

Much work has been done to document the health impacts of fine and ultrafine PM because of the deposition in the alveoli where exchange with the circulation may occur. Exercise seems to increase the deposition of PM in the lung, where epithelium damaged by the mechanical stress of high ventilation may allow PM to cross into the circulation (Rundell, 2012).

High PM concentration observed at athletic fields that are located close to major highways was found to affect the respiratory and circulatory systems of healthy athletes (ibid). In a second study thirty minutes of exercise in high PM concentration resulted in vasoconstriction of the brachial artery and a 55% decrease in re-oxygenation of muscle microvasculature leading to assumed decreases in muscle function. Esau et al found a considerable effect of PM on respiratory function in trained athletes, with increased PM exposure being directly correlated to decreased performance (Esau, Fletcher, & MacIntosh, 2008).

Acute inhalation of PM typical of an urban environment impairs both the systemic arterial function as well as the microcirculation and can result in decreased blood flow to the microvasculature. Exercise performance decreases in these high PM environments, in part due to impaired vasodilation in the peripheral vasculature (Rundell, 2012).

Performance impacts due to PM exposure may be delayed. Rundell found no performance impact when athletes exercised for 6 minutes in high concentrations of PM. However, a significant decline in performance was noted when the same exercise conditions were repeated three days later (ibid).

In another study athletes were exposed to PM for 20 minutes prior to a 6 minute, high intensity bike ride. Exercise performance was found to be decreased by 5% compared to pre-exposure levels (Brunekreef, Hoek, G, & Leentvaar, 1994). These results suggest that even a low intensity warm-up in poor air quality will result in decreased performance that may last for days.

OZONE: Ozone is a highly reactive gas, formed from the action of sunlight on hydrocarbons. Hydrocarbons are produced primarily by motor vehicles and a number of industrial sources. The highest levels of ozone are found on hot, bright days in rural areas. (Rojas-Rueda, de Nazelle, Tainio, & Nieuwenhuijsen, 2011).

Ozone acts as a respiratory irritant and triggers inflammatory molecules within the respiratory system at levels found in many metropolitan areas during the summer months (Mroszczyk-McDonald, ND). Perceptions of respiratory distress, pulmonary inflammation and decreased pulmonary function can result in decreased exercise performance. The ozone effects are amplified during exercise because of increased ventilation rate and volume as well as the bypassing of nasal filters due to oral breathing (Adams, 1987). Long term exposure to ozone is said to cause a premature aging of the lungs (Reynolds, Air pollution holds risks for athletes who exercise outdoors, 2007).

CARBON MONOXIDE (CO): The ability to generate prolonged energy depends on the extraction and transportation of oxygen to skeletal muscle. Carbon monoxide alters the ability of hemoglobin to carry oxygen. Hemoglobin also combines with CO to form carboxyhaemoglobin and has a 230 times greater affinity for CO than for O_2. Consequently, CO has a significant potential to alter the blood's oxygen carrying capacity and transport to muscle (Oliveira, et al., 2006).

Acute exposure to CO significantly decreased exercise performance in young healthy men when tested at concentrations similar to those found in urban environments (Adir, Merdler, Ben Haim, Front, Harduf, & Bitterman, 1999), Marr studied New York runners after 30 minutes of exercise near busy roads. He found an acute rise in carboxyhaemoglobin levels and estimated exhaustive exercise performed for 30 minutes in high traffic areas to be equivalent to smoking 10 cigarettes (Marr & Ely, 2010).

The increased carboxyhaemoglobin levels found after smoking or exposure to heavy pollution are shown to limit exercise performance in healthy subjects (Aronow & Cassidy, 1975).

SULPHUR DIOXIDE (SO_2): Sulfur dioxide is a highly water-soluble gas and is normally absorbed in the upper airway during nasal breathing. With heavy exercise, there is an increase in oral breathing and much larger amounts of sulfur dioxide are delivered to the lower airways. Several controlled human studies have shown that a combination of exercise and air pollutants such as ozone or sulfur dioxide cause a significant increase in bronchoconstriction and air flow obstruction when compared to the same exposure at rest (Pierson, 1989).

Asthmatics may be up to 10 times more sensitive to SO_2 than the general population and may experience significant airway resistance after just 5 minutes exposure at low levels.

NITROGEN DIOXIDE (NO_2): The main source of NO_2 is road traffic as seen through the correlation between high concentrations and major urban road networks ((Carlisle & Sharp, 2001) NO_2 is soluble and can be absorbed by the mucous lining of the nasopharynx. NO_2 can cause pharyngeal irritation, coughing and shortness of breath. Resistance to respiratory infection may also be decreased. Asthmatics have an increased sensitivity to NO_2 and changes to pulmonary function are found with repeated exposure in all populations.

Performance Impacts of Air Pollution

A great deal of work has been completed in an effort to quantify the performance impact of poor air quality. The physiological effects of high intensity exercise in high concentrations of mixed exhaust support the observed compromised performance (Rundell, 2012).

Through their own experiences and perceptions of respiratory distress some athletes are somewhat aware of the link between air quality and lung function. However, recent research suggests the cardiovascular impacts of poor air quality may be even greater than the respiratory effects. Because the link between cardiovascular function and air quality is complex, it may be more difficult to increase awareness of this health risk.

In his examination of Olympic athletes prior to the Vancouver Winter Olympic Games, McKenzie documented decreased oxygenation that led to a significant reduction in aerobic power and endurance during peak performance. A 1% decrease in aerobic capacity was found for every 1% decrease in arterial oxygenation. Air pollution is known to decrease arterial oxygenation and may amplify this affect (McKenzie & Boulet, 2008).

In another study, endurance decreased by 30% and lung function decreased by 22% when competitive cyclists were exposed to ozone while training. The same study revealed that ozone concentrations decreased by 50% for every 50m distant from traffic. (Helenius, Lumme, & Haahtela, 2005).

Health and Performance Guidelines for International Athletes

Scientists were asked by the medical staff of the Netherlands Olympic Committee to assess possible health effects of air pollution for athletes at the Athens Olympic Games. The following health recommendations were developed for all competing athletes (van Bree, 2009):

- To try to determine where high concentrations of particulate matter and ozone can occur, and avoid those locations if possible, including locations with heavy traffic;
- To choose accommodation and training facilities preferably at a location with relatively low air pollution;
- To reduce the amount of time spent outdoors and reduce physical exertion levels while outdoors.

These same recommendations were provided to athletes for the Beijing games.

PART 3: EVALUATING RISK AND AVOIDING EXPOSURE

As the first air quality and health index in the world, the AQHI has established credibility in air quality reporting. The AQHI science is well documented and continued research and investigation have served to further refine the Index's accuracy and usefulness for many different at-risk populations.

Athletes and the AQHI

Although the AQHI is now widely accepted within health and science communities, the *usefulness* of the Index for the athlete population still needs to be established.

Obvious strengths of the AQHI include the commitment to ongoing research and development as well as the real time reporting and forecasting features. The national network of reporting means that individuals within Canada can rely on the same information throughout the country.

That said, the AQHI has some inherent challenges that are yet to be resolved. One of the key ongoing concerns is the disconnect between perceived air quality as indicated by visibility and odour and the actual reported AQHI. Many of the pollutants that create a sensory degradation of air quality do not actually have a health impact and so are not included in the AQHI formula. Because of this, the perceived value of the Index is questioned. In some locations, the exclusion of location-specific pollutants of concern also bring into question the Index's usefulness.

From an athlete's perspective, the key challenges with use of the AQHI include the lack of multiple reporting stations and the extended 4-hour reporting cycle. As exposure to ozone and PM are extremely local, an AQHI reading for an entire community lacks the discrete reporting capabilities needed by athletes to limit exposure. Athletes and coaches can use community forecasts to plan training schedules but the AQHI cannot assist in limiting exposure based on location except for significant air quality events or persistent patterns of pollution. In addition the 4 hour reporting cycle is not frequent enough to allow athletes to plan – or alter - training schedules.

For competition hosts the AQHI monitor is generally not close enough to a proposed venue to help organizers choose one location over another or create policy to reduce air pollution close to a site.

The Future of Mobile Air Quality Sensing and Reporting

The AQHI has the potential to help athletes evaluate and avoid air pollution at major sporting competitions. As an example, the AQHI supports each of the recommendations for athletes provided by the Netherlands Olympic Committee in managing exposure to poor air quality at the Beijing Olympics.

In order to serve athletes and games organizers, the identified challenges associated with the Index need to be addressed – particularly the need to further develop mobile AQHI reporting. Several mobile air monitoring studies have found that the pollution levels identified by fixed monitors may not reflect the correct pollutant values of the area (Vardoulakis et al, 2005; Milton and Steed, 2007; Wallace et al, 2009).

If real-time mobile reporting can be achieved, the AQHI can help athletes limit the intensity and duration of exposure, it can help games organizers plan and control air quality at event venues and can help athletes identify training routes with the best air quality in any community. It is possible that these tools can be carried to overseas venues for use in regions without air quality reporting.

A number of projects have developed portable prototypes of air quality sensors that collect data from multiple sensors, geo-tag it, send it to a server and then provide feedback to the user.

Technological Advances in Canada

Mobile air quality sensing has been underway since 2005 with the introduction of the Canadian Regional and Urban Investigation System for Environmental Research – or Air Quality *CRUISER*. Highly sophisticated sensors are housed in a mobile air quality analysis vehicle which can then be driven to locations without a stationary sensor. It is possible that the CRUISER could be used to help Canadian competition hosts evaluate air quality at venues or along competition routes. However, because there is only one unit, its broad use is limited.

Through Environment Canada, work has begun to create cost-effective mobile sensors that report the health impacts of air pollution through the AQHI formula. Short term efforts are focusing on the development of small inexpensive sensors that could be used as mobile reporting stations. On a five-year horizon is the possibility of microtizing the same technology to be included in wrist and bike computers, tools already commonly in use by all athletes in training. The sensors could be programmed to be calibrated to individual air quality sensitivities and would help athletes evaluate and limit exposure even when there were no sensory changes in air quality.

San Diego - CitiSense

Mobile reporting is underway in San Diego where a citizen infrastructure now monitors pollution and environmental conditions. Personal smart phones equipped with small sensors collect data about select pollutants (CO, NO2 and O3) and environmental parameters (temperature, humidity and barometric pressure) and communicate this information via Bluetooth. The data is then used to provide real-time feedback to users and allows them to change their behaviour to avoid exposure to air pollution (Zappi, Bales, Park, Griswold, & Rosing, 2012).

The goal is to transform air quality monitoring in San Diego from five fixed EPA sensors to thousands of mobile sensors that feed air quality data to centralized computers – creating a network of real-time and hyper-local air quality reporting.

The San Diego technology is not immediately suitable for the athlete population because the sensors report single pollutants only and the cell phone is too cumbersome to be carried by a training athlete.

The San Diego research suggests that when users agreed to help report the air quality through personal mobile sensors, they also became more aware of air quality and took steps to minimize their exposure. The reporting tool helped educate users as to the risk (ibid).

Home-based Air Quality Reporting

An interesting recent development has been the introduction of personal air quality reporting sensors. As an example the Air Quality “Egg” is designed to give individuals a way to participate in the conversation about air quality. The egg includes a sensing device that measures the air quality in the immediate environment and that information is linked to an online community that is sharing this information in real-time (Sensemakers, 2012).

The Air Quality Egg senses and reports on NO2 and CO concentrations and lacks the sophistication of a health-based index, however its development signals a broader community interest in micro-air quality reporting.

PART 4: DISCUSSION

Many variables need to be optimized in order for athletes to achieve peak sport performance, including physical and mental training, rest, nutrition, equipment and tactics. Environmental factors, on and around, the competition venue are another significant consideration. Physiological challenges presented by environmental conditions such as extreme temperature and altitude are well established, but the connection between air quality and athletic performance is just starting to be understood.

Health and Performance

Research on air pollution's impact on peak performance is in its infancy. We know air pollution causes respiratory, cardiac and thrombolytic effects and it is probable that peak performance is also impacted. Current research infers this connection and anecdotal reports from elite athletes with and without asthma, support early research findings. Health impacts from exposure to air pollution have frequently been equated to the same exposure from second hand smoke (Marr & Ely, 2010).

It is not possible to physiologically prepare or condition athletes for exposure to poor air quality. And the impacts of air pollution are both immediate and long term, with some of the greatest restrictions occurring days after exposure. While waiting for research to support what is already assumed, the only ethical approach is to limit exposure during training and competition.

In an environment where each athlete is looking for a competitive advantage, and games organizers are working to provide the best technical venue possible, managing air quality at competition venues must be considered as one of the key factors for success.

AQHI Uptake

We know from a review of behaviour during the 2009 BC forest fires that when people see or smell poor air quality they are more likely to take actions to minimize exposure. We also know that people rely on their sensory perceptions to evaluate air quality. The AQHI allows Canadians to more accurately evaluate local air quality and take precautions when the pollution levels are high but may not be perceptible through the senses.

In order to help limit the exposure of elite athletes to poor air quality, we first need to advance AQHI sensors and reporting to better meet their needs – including the development of mobile sensors. When the technology can be microtized and is inexpensively available for all athletes, then the AQHI can become a seamless part of a training program and help reduce the health impacts to this risk group.

As seen with the introduction of the AQHI to other risk populations, individuals first need to understand and experience the impacts of air quality before engaging with the Index. With that in mind, one effective way to increase acceptance with the elite athlete community is to showcase the AQHI at a major sporting event so that competitors can experience the potential benefit of air quality event management through the Index.

The Toronto Host Committee of the 2015 Pan Am Games has already expressed interest in integrating the AQHI into the Games. Summer weather and traffic patterns in Toronto are likely to lead to periods of poor air quality during the Games, which may threaten the reputation of the host community or the success of the Games itself, as seen in the Beijing and London Olympic Games.

Through working with the Pan Am Games Host Committee, there are unique opportunities to reduce exposure and increase visibility of the AQHI, including:

- Showcase the AQHI as a means of addressing concerns about air quality
- Protect athletes health
- Create the environment for athletes' peak performances

- Increase Canadian and international awareness of the health and performance impacts of poor air quality
- Meet Toronto's ethical and legal obligations to provide a safe competitive environment
- Provide sustainability and legacy requirements

An alternative target event is the 2015 Women's World Cup held in multiple urban centres throughout Canada.

Legal and Ethical Obligations

Note: This review of the ethical and legal obligations of event organizers has been provided by Jon Heshka, Law Professor (sport law specialty), Thompson Rivers University. Jon is an associate editor with the International Journal of Sport and Society and sits on the International Association of Sports Law sports safety committee and scientific committees. Jon is a Co-Director at the Centre for International Sports Law at Staffordshire University.

Major games and international sporting events are held in large cities where air quality is inevitably bad and smog conditions are of concern to human health. The exposure to particulate matter and ozone threaten the health of athletes and may adversely affect their performance.

Event organizers have a general duty to provide reasonably safe environments for athletes to compete and a reasonably safe work environment for its employees and volunteers. To the extent that air pollution compromises the health of its athletes and workers/volunteers, the event organizers are limited by the extent to which they can take affirmative and corrective action to fix the problem. Unlike a defective bleacher or building that would fall under the event organizer's ambit under common law and occupiers' liability (meaning they would have a duty to repair it to ensure it was in reasonable working condition), event organizers do not control the atmosphere and thus are in no position to guarantee good air. In short, there is no duty in law to ensure clean air.

However, there is a clear ethical duty to take action to minimize the risk to athletes from all environmental factors including poor air quality. This duty involves taking specific actions to reduce known pollutant sources and make informed choices about competition courses and venues.

For reasons previously stated, there is a business case to be made that clean air equates to clean races and fast times. The term 'clean races' typically refers to races devoid of athletes taking performance enhancing drugs (PEDs) which have been declared illegal by the World Anti-Doping Agency (WADA - based in Montreal) and the International Olympic Committee. One of the three criteria against which something is included on WADA's Prohibited List is whether it presents an actual or potential health risk to the athlete. In this current context, clean races would mean races bereft of harmful air pollutants which would be consistent in principle with the WADA Code.

Canadian Air Quality – A Competitive Advantage

Increasingly athletes will demand that games organizers address air pollution when hosting competitive events. If concerns are not addressed, hosts not only risk penalties such as the reported £300 million fine London faces for non-compliance with EU standards, but they also face the possible withdrawal of high profile competitors as well as loss of sponsorship.

Canada enjoys relatively good air quality in most of the major urban centres that have potential to host national and international sporting events. With the addition of a mobile air quality monitoring tool such as the AQHI, communities bidding for host opportunities could highlight air quality and reporting as a competitive advantage over other locations.

In addition, the AQHI could help Canadian games organizers meet their sustainability and legacy commitments developed as part of the bid process.

Enhanced AQHI reporting and community awareness could form part of a public education campaign that results in a community legacy of reduced exposure to poor air quality for all athletes and residents alike.

IMPLICATIONS FOR GAMES AND EVENT ORGANIZERS

It is clear that from health, performance and reputation management perspectives, Games organizers will increasingly need to consider management of air quality as part of their event preparations. In strenuous athletic competition such as the Olympic Games where small increments of time often determine the ultimate success of athletes, the impact of air pollutants and subsequent adverse cardiovascular and respiratory changes can affect athletic performance.

Course Design and Event Scheduling

Because of the health and performance impacts described previously, it is suggested air quality be considered as a condition for course design / race scheduling for long distance running and cycling events. For example, while event organizers must work with city planners to minimize traffic disruption to the host city, this often means that there are lanes of traffic along the race route while the race is being run. While the advantage to drivers is obvious, the downside to athletes is equally self-evident. The recommended solution is to make set-backs mandatory so that no athlete is closer than 50 metres to an open traffic lane as recommended through the findings of Helenius et al. The optimal solution would be to close off all lanes in the vicinity of the race thereby minimizing the amount of pollutants emitted into the air.

Other issues include the location of the race itself. In order to optimize the spectator experience, races are often located in central urban areas. Considerations affecting where the course is set include how best to get athletes to the starting line and away from the finish line, the movement of spectators along the race course, and minimizing traffic disruption to city residents. Rarely is the traffic impact on athletes considered as part of event planning.

Creating Opportunities for Peak Performance

High performance athletes are aware of the conditions which will give them the best chance to compete at the highest level. Most of the best athletes set competition schedules far in advance to enable them to peak for certain events.

At issue then is what inspires athletes to compete in certain events. Courses with a reputation for being flat and fast (within IAAF course parameters), with favorable weather and winds are geared to offering athletes an opportunity to go their fastest. Courses with the opposite reputation – or those rumoured to be disadvantageous to fast times – will not attract top talent, inevitably resulting in slow courses with slow athletes producing slower times.

For example, runners who wish to represent Canada on the international stage, i.e. the Olympics or World Championships, must qualify and meet a time requirement. Courses which are conducive to these times will attract individuals who think they can do it. Having a course where air quality is taken seriously by event organizers thereby maximizing the opportunity for athletes to attain fast times will get the attention of high performance runners.

It may be argued that air pollution impacts all athletes equally and would not create an unfair competitive advantage for one athlete over another. But because air pollution affects athletes differently, some elite athletes would have a de facto advantage over those who are less sensitive. All athletes would be exposed to short and long term health risks.

Marketing and Sponsorship

Attracting corporate sponsorships is critical to national and international event hosts. Sponsors are looking for the highest visibility possible in return for their investment – and participation by high profile athletes increase visibility. If event organizers create conditions that offer the potential for world record performances, high performance athletes are more likely to compete, broadening the opportunity to attract sponsors.

PART 5: FUTURE OPPORTUNITIES

A unique convergence of technology, science and interest provides an opportunity to showcase Canada's environmental and technological leadership as well as increase the use of the AQHI among elite athletes,

The following series of recommendations support the development of mobile AQHI technology and showcasing that work through a high profile competitive event. Through the use of the AQHI in the planning and hosting of the event, athlete and coach awareness – as well as international attention - will be increased.

Recommendations:

1. Continue to support research into development of mobile AQHI reporting technology.
2. Identify a high profile Canadian national or international competition to showcase AQHI technology. Recommended event - 2015 PanAm Games in Toronto.
    - Work with Games organizers to use mobile AQHI to evaluate and plan training and competition venues.
    - Use competitive event to begin to showcase the AQHI technology internationally.
    - Plan a campaign to proactively promote the AQHI and its role in managing air quality during the Games.
    - Use event to educate all audiences.
    - Consider role of AQHI in meeting host community sustainability and legacy commitments.
4. Work closely with Paralympic athlete community to determine and address unique needs.

Bibliography

Adams, W. (1987). Effects of ozone exposure at ambient air pollution episode levels on exercise performance. *Sports Med*, 395-424.

Adir, Y., Merdler, A., Ben Haim, S., Front, A., Harduf, R., & Bitterman, H. (1999). Effects of exposure to low concentrations of carbon monoxide on exercise performance and myocardial perfusion in young healthy men. *Occup Environ Med*, 535-8.

Aronow, W., & Cassidy, J. (1975). Effect of carbon monoxide on maximal treadmill exercise. A study in normal persons. *Annals of Internal Medicine*, 496-9.

Bernhardt, G. (2008). *Smogging the compeition: Polluted air and athletes*. Retrieved 3 28, 2012, from active.com: www.active.com/page20609.aspx

Brunekreef, B., Hoek, G, B. O., & Leentvaar, M. (1994). Respiratory effects of low-level photochemical air pollution in amateur cyclists. *Am J Resp Crit Care Med*, 962-6.

Carlisle, A., & Sharp, N. (2001). Exercise and outdoor ambient air pollution. *Br J Sports Med*, 214-222.

Esau, S., Fletcher, J., & MacIntosh, B. (2008). The effects of air quality index on the respiratrory function of disabled athletes. *Medicine and Science in Sport and Exercise*, S362-S363.

Helenius, I., Lumme, A., & Haahtela, T. (2005). Asthma, airway inflammation and treatment in elite athletes. *Sports Med*, 565-574.

Lippi, G., Guidi, G., & Maffulli, N. (2008 Aug;29(8)). Air pollution and sports performance in Beijing. *Int J Sports Med*, 696-8.

Marr, L., & Ely, M. (2010). Effect of air pollution on marathon running performance. *Medicine Science Sports and Exercise*, 585-91.

McKenzie, D., & Boulet, L. (2008). Asthma, outdoor air quality and the Olympic Games. *Canadian Medical Association Journal*, 543-548.

Mills, N., Donaldson, K., Hadoke, P., Boon, N., MacNee, W., Cassee, F., et al. (2009). Adverse Cardiovascular Effects of Air Pollution. *Nat Clin Pract Cardiovasc Med*, 36-44.

Mills, P., & Krassioukov, A. (2011). Automanic function as a missing piece of the classification of Paralympic athletes with spinal cord injury. *Spinal Cord*, 768-76.

Mroszczyk-McDonald, A. (ND). *Athletes and Air Pollution.* Retrieved 3 28, 2012, from Body Health: www.bodyhealth.com/html/biobbuilde/alex4

Oliveira, R., Barros Neto, T., Braga, A., Raso, V., Pereira, L., Morette, S., et al. (2006 Dec;39(12)). Impact of acute exposure to air pollution on the cardiorespiratory performance of military firemen. *Braz J Med Biol Res.*, 1643-9.

Pierson, W. (1989). Impact of air pollutants on athletic performance. *Allergy Proc*, 209-14.

Piturro, M. (2008). Beijing's air quality affects Olympic athelete's performance. *ENT Today*.

Reynolds, G. (2007). Air pollution holds risks for athletes who exercise outdoors. *New York Times*.

Reynolds, G. (2007, 12 7). Air pollution holds risks for athletes who exercise outdoors . *New York Times*.

Reynolds, G. (2012, 4 1). *Exercising outdoors: How does pollution affect athletes?* Retrieved 1 15, 2012, from International Herald Tribune: www.active.com/page22300.aspx

Rojas-Rueda, D., de Nazelle, A., Tainio, M., & Nieuwenhuijsen, M. (2011). The health risks and benefits of cycling in urban environments compared with car use: Health impact study. *BMJ*.

Rundell, K. (2012). Effect of air pollution on athlete health and performance. *Br J Sports Med*.

Sensemakers. (2012). *Air Quality Egg*. Retrieved April 12, 2012, from Kickstarter: www.kickstarter.com/projects/edborden/air-quality-egg

Shaffer, H., Rodriguez-Colon, S., Yanosky, J., Bixler, E., Casio, W., & Liao, D. (2011). Acute effects of ffine particle air pollution on cardiac arrhythmia. *Environ Health Perspect*, 927-32.

Sharman, J., Cockcroft, J., & Coombes, J. (2004; 97). Cardiovascular implications of exposure to traffic air pollution during exercise. *QH Med*, 637-643.

Sombach, D. (2012, February 22). *LOCOG Ignores Air quality at london Olympics*. Retrieved 3 12, 2012, from East London Olympics: http://eastlondonolympics.co.uk/olympic-news/organisation/2012/02/will-london%E2%80%99s-air-quality-be-an-issue-during-the-games/

Stanford, B. (1990; 18: 153-154.83). Exercise and air pollution. *Phys Sportsmed*, 496-499.

Stieb, D. (2011). Effects on exposure and dose of changing activity, time and location. *6thAnnual Air Quality and Health Workshop.* Vancouver.

Stieb, D., Szyszkowicz, M., Rowe, B., & Leech, J. (2009). Air pollution and emergency department visits for cardiac and respiratory conditions: a multi-city time-series analysis. *Environmental Health*, 8-25.

Theisen, D. (2012). Cardiovascular determinants o exercise capacity in the Paralympic athlete with spinal cord injury. *Exp Physiol*, 319-24.

Unal, M., Sahinkaya, T., Namarash, D., Akkaya, V., & Kayserilioglu, A. (2004). The prevelance of exercise induced bronchospasm in elite athletes. *Journal of Sports Science and Medicine*, 57-59.

van Bree, L. (2009). Air Quality and the Olympics. *EnviroSci News*.

Vidal, J., & Gibson, O. (2011, April 24). *London Olympics pollution on course to land Britain hefty fine from IOC*. Retrieved March 14, 2012, from The Guardian: http://www.guardian.co.uk/environment/2011/apr/24/london-olympics-pollution-fine-ioc

Weichenthal, S., Kulka, R., Dubeau, A., Martin, C., Wang, D., & Dales, R. (2011). Traffic-related air pollution and acute changes in heart rate variability and respiratory function in urban cyclists. *Environmental health perspectives*, 1373-1378.

Wilber, R. (2008, August 4). Physiologist US Olympic Committee. (B. A. Bowser, Interviewer)

Wilber, R., Rundell, K., Szmedra, L., Jenkinson, D., & Drake, S. (2000). Incidence of exercise-induced bronchospasm in Olympic winter sport athletes. *Med Sci Sports Exercise*, 723-737.

Zappi, P., Bales, E., Park, J., Griswold, W., & Rosing, T. (2012). The CitiSense air quality monitoring mobile sensor node.