

# **Air Pollution and Physical Activity:**

## **Examination of Toronto Air Data to Guide Public Advice on Smog and Exercise**

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## EXECUTIVE SUMMARY

Air pollution continues to pose a significant health risk to the Toronto population. While actions to improve air quality are of paramount importance, progress is slow. Trend data for key air pollutants with adverse health effects on the Toronto population reveal little improvement in air quality over the last two decades in this city. With climate change and the associated increase in hot sunny days, the number of smog alert days (also known as smog advisory days) is likely to increase. With each smog alert, health officials reiterate precautionary messages to reduce vigorous physical activity outdoors so as to minimize the intake of air pollutants. This presents a dilemma because regular physical activity has a profound and positive influence on people's health.

This study was undertaken to determine when and where air pollution levels tend to be lowest so that the public can plan its exercise programs accordingly. Mean hourly pollutant levels for Toronto were calculated for those days in which the air quality index (AQI) was less than 50 (i.e. 'good' and 'moderate' air quality days), and those days when the AQI was 50 and greater (i.e. 'poor' air quality days). The times of day when hourly pollutant levels were below daily means, were determined. Pollutants vary in their temporal distribution, with concentrations of some pollutants (such as ozone, particles and sulphur dioxide) being highest during mid-day, and others (such as carbon monoxide and nitrogen dioxide) being highest with morning rush hour. Overall, pollutant levels tend to be lowest in low traffic areas *and* before 7 a.m. and after 8 p.m.

This study offers some guidance to Toronto residents for maximizing physical activity while minimizing exposure to air pollutants. More research is required to guide development of health protective advice that takes into account the health benefit of regular exercise (even during times of moderately elevated air pollution) and identifies possible modifications in activity patterns to lessen health risk from air pollution. Research is also required to better characterize pollution levels in a variety of indoor settings, such as homes, schools, childcare facilities, and sports and recreational centres, in comparison with outdoor pollution levels. This type of information would be beneficial to staff and parents supervising children at schools, summer camps, day cares and recreational facilities who need to develop sound policies regarding physical activity on days with poor outdoor air quality.



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## INTRODUCTION

Trend data for key air pollutants with adverse health effects on the Toronto population reveal little improvement in air quality over the last two decades (Toronto Public Health, 2001a). Nitrogen dioxide (NO<sub>2</sub>) levels appear to be increasing slightly, whereas total suspended particles (TSP) and respirable particulate matter (particles of diameter less than or equal to 2.5 microns, PM<sub>2.5</sub>) appear to be decreasing somewhat. Carbon monoxide (CO), sulphur dioxide (SO<sub>2</sub>) and ozone (O<sub>3</sub>) levels show no consistent reductions overall since 1980 (Toronto Public Health, 2001a).

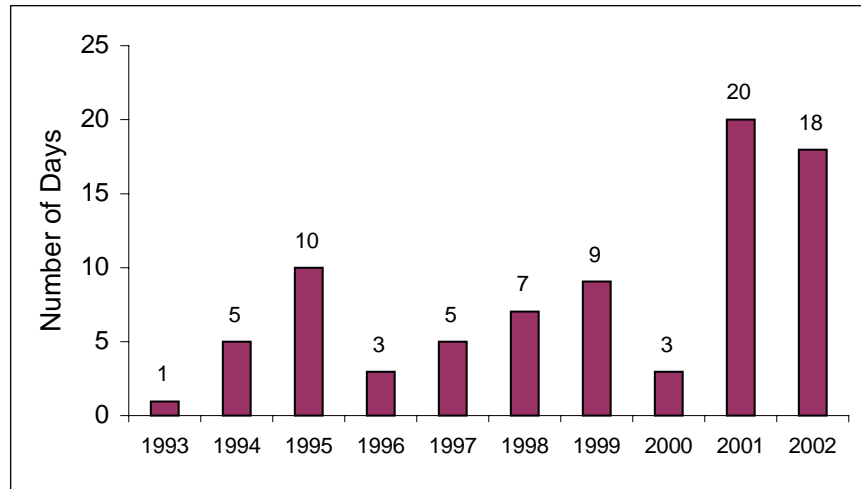
Five common air pollutants – ozone, inhalable particles (particles of diameter less than or equal to 10 microns, PM<sub>10</sub>), NO<sub>2</sub>, SO<sub>2</sub> and CO – are estimated to contribute to about 1,000 premature deaths and 5,500 respiratory and cardiac hospitalizations each year in Toronto (Toronto Public Health, 2000). Despite many initiatives to improve air quality in the City, progress is slow. A number of smog advisory days (also referred to as ‘air quality advisories’ or ‘smog advisories’ by the Ontario Ministry of the Environment, and ‘smog alerts’ by Toronto Public Health) occur every year in Toronto, as shown in Figure 1 (Toronto Public Health, 2001b). Although it is too early to tell, there is concern that climate change and the anticipated increase in hot sunny days may lead to even more smog alerts in the future.

The Ontario Ministry of the Environment (OMOE) issues an air quality advisory (or smog advisory) when an Air Quality Index (AQI) value of 50 or greater is expected to be widespread and persistent. At an AQI of 50 or higher, air quality is described as ‘poor’. Because the smog advisory is regional in nature, some local areas may be experiencing poor air quality, even though an advisory has not been called. The OMOE makes all current and forecasted AQI values accessible to the public through its web site and telephone information line. The purpose of the ‘smog advisory’ or ‘smog alert’ is to enable the public, including sensitive subpopulations with breathing and heart problems, to take special precautions to protect their health. Precautions include reducing vigorous physical activity outdoors, drinking plenty of fluids (especially when smog alerts occur on high heat days) and ensuring proper use of medication as directed by a physician.

In August 2002, the Ontario Ministry of the Environment improved the AQI by including respirable particles (PM<sub>2.5</sub>) in the index, to better reflect actual air quality. As a result, it is likely that the AQI will indicate a greater number of days with poor air quality (i.e. AQI ≥ 50) in future years. Although it is important to encourage the public to limit vigorous physical exertion outdoors when the AQI is 50 or greater, there is also a need to reinforce the health benefit

of regular physical activity. This investigation was undertaken to determine when and where air pollution levels tend to be the lowest during the day to serve as a guide for minimizing exposure to air pollutants while engaging in vigorous physical activity.

**Figure 1: Number of Smog Advisory Days in Toronto (a)**



- (a) The number of days for which OMOE issued Air Quality Advisories (also known as Smog Advisories) during each respective year.

## HEALTH BENEFITS OF PHYSICAL ACTIVITY

### Health Benefits

Regular physical activity has a profound and positive influence on the health of people at all stages of their life. Scientific studies have demonstrated that a lack of physical activity is associated with increased disease and premature mortality. Researchers estimate that 21,000 premature deaths, and 2.5% of the total direct health costs in Canada (\$2.1 billion), were attributable to physical inactivity in 1999 (Katzmarzyk et al., 2000).

The absence of regular physical activity is associated with increased risk of cardiovascular disease, diabetes, osteoporosis, obesity and mental health concerns.

Regular physical activity, resulting in cardiorespiratory fitness, decreases the risk of coronary heart disease, including heart attacks. Regular exercise also lowers the risk of developing Type 2 diabetes (National Health Committee, 1998). More than 1.8 million Canadian adults are affected by Type 2 diabetes, which may result in accelerated development of cardiovascular disease, renal failure, loss of vision and limb amputations (Canadian Diabetes Association, 2002).

Regular exercise helps protect against osteoporosis (loss of bone mass and strength) in the elderly. Osteoporosis affects about 25% of women and half as many men over the age of 50 (Hanley and Josse, 1996). Physical activity, especially weight bearing exercise, helps build greater bone density in childhood and adolescence, as well as maintain peak density in adulthood. Regular exercise protects against falls in the elderly by increasing muscle strength and balance. Exercise reduces the risk of falls by about 25%. Falls are a major cause of fractures in people with osteoporosis (U.S. Department of Health and Human Services, 2002).

Regular physical activity is associated with good self-esteem and sense of control over life (Martin and Wade, 2000). A lack of physical activity often coincides with increased sedentary behaviour such as watching television, playing video games and using computers. Extensive watching of television is strongly associated with increased risk of obesity because it involves decreased energy expenditure, and often increased energy intake from high-fat snack foods. Juvenile obesity is associated with poor self-esteem, depression and social discrimination (Canadian Paediatric Society, 2002).

## Physical Activity Guidelines

Health Canada and the Canadian Society for Exercise Physiology (1998) recommend that adults accumulate at least 60 minutes of light physical activity (daily), or 30 to 60 minutes of moderate activity (four days per week), or 20 to 30 minutes of vigorous activity (four days per week) to stay healthy or improve health. Table 1 indicates that substituting vigorous activity for light effort reduces the recommended minimum amount of time to exercise each day.

**Table 1. Physical Activity Guidelines for Adults**

Types of Activities	Examples	Duration (minutes)	Frequency
Light effort	Slow pace walking Stretching Volleyball Easy gardening	60	daily
Moderate effort	Brisk walking Bicycling Raking leaves Slow to moderate dancing Water aerobics	30 – 60	4 times per week
Vigorous effort	Aerobic workout Jogging Hockey Basketball Fast Dancing	20 - 30	4 times per week

Older adults are encouraged to undertake 30 to 60 minutes of moderate activity every day. Older adults should also do daily exercises to increase flexibility, and exercises to increase strength and balance two to four times per week (Canadian Society for Exercise Physiology and Health Canada, 1999). Inactive children are encouraged to increase their physical activity levels by 90 minutes each day. The increase in physical activity should include a combination of moderate activity (such as brisk walking, skating and bicycling) and vigorous activity (such as running and playing soccer) (Health Canada and Canadian Society for Exercise Physiology, 2002).

## Activity Levels and Respiratory Rates

The greater the activity level, the higher the respiratory rate and resultant intake of air. The relationship between age, activity level and hourly respiratory rate is shown in Table 2. For a healthy adult male, one hour of heavy activity would be equivalent in terms of respiratory rate to about 7 hours at rest. For a child (between 6 and 13), vigorous activity (such as playing soccer) will result in about 5 times the inhalation rate as sitting playing computer games.

The amount of air pollutants that people take into their lungs depends on many factors, including their activity level and resultant respiratory rate, their mode of breathing, and the concentration of pollutants at that particular time and microenvironment. Vigorous exercise is known to increase the respiratory rate and change the mode of breathing from through the nose to through the mouth, thereby by-passing the ability of the nose to filter some pollutants (Tarlo et al., 1990).

Typically, a young child will inhale approximately 5 times more air per kilogram of body weight per day than an adult does. In a given microenvironment, children receive a higher dose of air contaminants compared to adults because of generally higher activity levels and respiratory rates (Toronto Department of Public Health, 1994).

As seen in Table 2, heavy (vigorous) activity such as running results in more than twice the inhalation rate as light activity such as walking slowly. Consequently the intake of air pollutants is more than twice as high during running compared with walking.

It is noteworthy that exercise increases respiratory efficiency so that a fit person actually inhales less air than does an unfit person undergoing the same level of physical activity. As a result, pollutant exposure will be lower in the fit person compared with the less fit individual.

**Table 2: Average Inhalation Rates by Age Group and Activity Level**

Activity Level	Activity Description	Average Inhalation Rate (m <sup>3</sup> /hour)		
		Children (6 to 13 yr)	Adult Females (all ages)	Adult Males (all ages)
Resting	Lying	0.45	0.43	0.54
Sedentary	Sitting or standing	0.47	0.48	0.60
Light	Walking slowly (2.4 – 4.8 km/hr)	0.95	1.33	1.45
Moderate	Walking quickly (5.3 – 6.4 km/hr)	1.74	2.76	1.93
Heavy	Running quickly (7.2 – 9.6 km/hr)	2.23	2.96	3.63

Source: U.S. Environmental Protection Agency, 1997.

## HEALTH CONCERNS ABOUT AIR POLLUTION

### Adverse Health Effects

Over the last decade, a large body of scientific evidence has accumulated that confirms that air pollution, even at the levels experienced in major urban centres such as Toronto, adversely affects the health of children and adults (Burnett et al., 1998; Burnett et al., 1999; Stieb et al., 2002; Vedal et al., 2003). Effects are wide ranging, and include reduced lung function, acute and chronic bronchitis, asthma attacks, emergency room visits, increased hospitalizations for respiratory and cardiac causes, elevated mortality rates, and increased incidence and duration of respiratory symptoms. New studies link air pollution with lung cancer, heart attacks, strokes, high blood pressure and congenital heart defects. These studies identify asthmatics, diabetics and those with congestive heart failure as being at particularly elevated risk from air pollution (American Lung Association, 2002).

Toronto Public Health, in its previous study *Air Pollution Burden of Illness in Toronto* estimated that five common smog-related pollutants contributed to about 1,000 premature deaths and 5,500 hospitalizations for respiratory and cardiac causes in 1995, the base year for the study (Toronto Public Health, 2000). Given that average pollution levels have remained relatively steady in the City since 1995, it is reasonable to expect a similar level of air pollution-related health burden at this time.

In May 2002, the discovery of a software problem in the S-PLUS statistical package (in widespread use among international air quality investigators, especially those involved in time-series studies) raised concerns in the scientific community that some estimates of premature mortality and illness may have been overestimated in studies using this software. Since then, some risk estimates (such as for particles -  $PM_{2.5}$  and  $PM_{10}$ ) have been re-analyzed with corrected S-PLUS software and an alternative model. The central findings of previous epidemiological studies showed a statistically significant association between particulate matter and adverse effects, and the re-analysis did not change these results (Colburn and Johnson, 2003). However, the magnitude of the effect of particulate matter is somewhat lower than previously reported. Further review and reanalysis of the S-PLUS problem is underway.

The best estimate to date of the air pollution-related burden of illness for the Toronto population arising from exposure to key pollutants found in smog continues to be about 1,000 premature deaths and 5,500 hospitalizations each year. This estimate reflects primarily acute health impacts, and does not fully account for effects due to chronic exposure of pollutants, nor does it take into

account adverse effects from carcinogens such as benzene, 1,3-butadiene and polycyclic aromatic hydrocarbons (PAHs).

### **Impact of Exercise During Exposure to Pollution**

Although the relationship between exercise and adverse impacts arising from breathing polluted air is not fully understood at this time, numerous studies have shown increased impacts with increased activity levels. These effects tend to be most pronounced in people with underlying health conditions such as asthma.

Through the use of chamber studies (which involve a controlled indoor environment in which pollutant levels are varied), it has been shown that increasing the intensity of exercise while exposed to ozone adversely impacts lung function and increases reporting of symptoms (Adams, 2000). In another chamber study, exposure to ozone during exercise had a much greater adverse impact on the lung function of men with chronic obstructive lung disease compared with healthy subjects (Gong et al., 1997).

A study of adult hikers found that with prolonged hiking in an outdoor setting, exposure to ozone, PM<sub>2.5</sub> and acid aerosols was associated with significant impacts on pulmonary function. Hikers with asthma or severe wheeze showed the greatest adverse impacts (Korrick et al., 1998).

A review of British studies involving athletes concluded that outdoor exposure to CO (such as occurs near traffic) is detrimental to athletic performance and that ozone adversely impacts lung function and likely athletic performance (Carlisle and Sharp, 2001). The study also found that for athletes with asthma even low levels of SO<sub>2</sub> result in problems, such as wheezing, chest tightness and increased airway resistance. Asthmatics are generally ten times more sensitive to SO<sub>2</sub> than non-asthmatics, especially when exercising (Carlisle and Sharp, 2001).

No studies were found that provide evidence-based guidance on ways to lessen the adverse impact of exercise in polluted outdoor environments, such as through intermittent exercise (with rest periods), prolonged exercise at lower intensity, or shifting exercise to indoor environments. One study showed that there was no difference in lung function due to ozone between continuous and intermittent exercise, however subjective symptoms were somewhat reduced when exercise involved rest periods (McKittrick and Adams, 1995).

## Comparison of Indoor and Outdoor Pollution Levels

It is of interest to understand how outdoor concentrations of the common pollutants included in the air quality index (AQI) compare with concentrations of these same pollutants indoors. It is also important to consider the relative distribution of trace air toxics. By examining whether the public's exposure to air pollutants tends to be higher or lower indoors relative to outside, one could provide guidance to the public regarding physical activity when outdoor air pollution levels are elevated.

While some useful information exists from studies in other countries regarding the distribution of pollutants among indoor and outdoor environments, only limited information is available for Canadian cities. Of particular benefit would be studies that compare indoor and outdoor pollutant levels at a variety of settings such as schools, child care facilities, recreational and sports centres, and homes. For homes, it would be useful to compare pollutant levels in residences with and without air conditioning, and those located in high and low traffic areas, so as to assess pollutant levels inside the home during periods of moderate or poor air quality compared with outdoor levels. This type of information would be especially useful for large urban centres, such as Toronto, given its high vehicle density and proximity to upwind sources of transboundary pollutants. However, there is also a need to assess indoor/outdoor relationships in a variety of communities across Canada, given the variability in pollution levels in both indoor and outdoor environments.

The following section provides a brief overview of some recent studies that measured indoor and outdoor pollutant levels. It is typical for indoor settings to show large variability in pollutant levels. This is in large part due to pollutant infiltration rates from outdoors, pollutant levels outdoors, air exchange rates, presence of air filtration or air conditioning systems, and indoor sources such as smoking, cooking, cleaning and hobbies.

There is some evidence that air pollution levels indoors may be lower in homes with air conditioning compared to homes without, however, more research is required in this area. For example, ozone (Lee et al., 1999), PM<sub>2.5</sub>, PM<sub>10</sub> and SO<sub>2</sub> levels (Leaderer et al., 1999) were lower in air-conditioned homes than in those without air conditioning. The extent to which this is due to decreased infiltration of outdoor air pollutants into air-conditioned homes as compared to the level of infiltration into non-air-conditioned homes where windows may be open more frequently is not known.

**(a) AQI Pollutants**

Based on published studies in other cities, particle levels (PM<sub>10</sub> and PM<sub>2.5</sub>) are typically lower inside homes (without smokers) than outside. Particles (PM<sub>10</sub> and PM<sub>2.5</sub>) in the home typically originated from outside sources (Colome et al., 1992), especially when the home was close to high traffic areas (Kingham et al., 2000; Funasaka et al., 2000). Particle levels were about 70% to 80% as high indoors as outdoors (Colome et al., 1992; Kingham et al., 2000). Homes with smokers or non-airtight wood stoves and fireplaces have much higher levels of PM<sub>10</sub> and PM<sub>2.5</sub> than those homes without such sources (Jones, 2000; Koutrakis et al., 1991; Dimitroulopoulou et al., 2001). These homes are likely to have higher levels of PM<sub>10</sub> and PM<sub>2.5</sub> indoors than outdoors. A study of Toronto homes (Crump, 2000) found PM<sub>2.5</sub> levels inside the homes of non-smokers to be somewhat lower than outside, however, the indoor levels were more variable.

Levels of nitrogen dioxide in the home are heavily influenced by the presence of indoor sources, such as gas appliances (for example, gas stoves in the kitchen), kerosene heaters and wood stoves (Jones, 2000). Where indoor emission sources were not present, NO<sub>2</sub> levels generally correlate well to those observed outdoors (Jones, 2000). The temporal distribution of hourly NO<sub>2</sub> levels of inside the home is important to note. Gas cooking produces large intermittent increases in NO<sub>2</sub> levels in the kitchen, with large peaks corresponding to the time of breakfast and dinner preparation (Dimitroulopoulou et al., 2001). However, at non-peak times, NO<sub>2</sub> levels tended to be low.

Sulphur dioxide levels are typically lower indoors than outdoors (Jones, 2000; Bell et al., 1994; Pengelly et al., 1997). Levels in homes without significant sources have indoor levels of SO<sub>2</sub> at 10 to 60 percent of the levels outdoors (Jones, 2000). However, homes with kerosene heaters and poorly vented gas appliances can have greatly elevated levels of SO<sub>2</sub> inside the home (Jones, 2000).

Ozone levels are also typically lower indoors than outdoors unless there are specific indoor sources. Indoor sources of ozone include photocopiers, electrical equipment and improperly installed or maintained electrostatic air cleaners (Toronto Department of Public Health, 1994).

The level of carbon monoxide in air tends to be higher inside the home than outside. Significant indoor sources of CO include automobile exhaust from attached garages, blocked chimneys, faulty gas appliances and tobacco smoke. Levels of CO are somewhat higher in homes with gas appliances (stoves, water heaters, furnaces) than in homes with electric appliances (Toronto Department of Public Health, 1994).

In Toronto, smog alert days occur when ozone or PM<sub>2.5</sub> levels are especially high. Given that ozone and particle levels are lower inside the home than outside, exposure to these two pollutants during smog alert days would be less inside than outside. However, there are other pollutants that might be in the home, and thus it is important to also consider how the levels of these pollutants indoors compare with levels outdoors.

### **(b) Trace Air Toxics**

Studies show that levels of many volatile organic compounds or VOCs (for example, toluene, xylenes, formaldehyde, chlorinated methanes) and some aromatic hydrocarbons tend to be higher inside the home when compared to levels outdoors (Kim et al., 2001; Bell et al., 1991, 1994; Ilgen et al., 2001). Levels of metals (such as manganese, chromium, cadmium and lead) tend to be higher outdoors than indoors (Bell et al., 1994; Pengelly et al., 1997). Polycyclic aromatic hydrocarbons (PAHs) include many different hydrocarbons, some of which occur at higher levels indoors, and others at higher levels outdoors (Naumova et al., 2002). Carcinogens, such as benzene, 1,3-butadiene and benzo[*a*]pyrene, have been observed to be lower inside the home than outside (Pengelly et al., 1997).

A detailed study of six aromatic hydrocarbons (benzene, toluene, ethylbenzene and three xylenes) in relation to traffic is particularly relevant. The study examined the influence of vehicle exhaust on indoor pollution from aromatic hydrocarbons (Ilgen et al., 2001). The study found that although benzene levels in high traffic areas (urban versus rural setting) showed high peak values during morning and evening rush hour, indoor levels remained relatively low and constant throughout the 24-hour period. The study also found that by closing windows on the street side of the home, the penetration of pollutants inside is slowed, making it possible to avoid exposure to peak concentrations during rush hour. Pollutant levels were significantly decreased outdoors with height above street level (Ilgen et al., 2001).

### **(c) Overview of Where Pollutants Tend to be Lowest**

In general, there is a lack of good exposure assessment data in Ontario communities regarding concentrations of air pollutants in indoor environments. Some older studies conducted in Toronto (Bell et al., 1991), Windsor (Bell et al., 1994) and Hamilton (Pengelly et al., 1997) do provide useful observations. These studies, along with studies from other countries, suggest that many of the pollutants associated with significant health risk occur at higher levels outdoors than inside the homes of non-smokers. The levels of many pollutants, including VOCs and particles, typically are much higher in the homes of smokers than non-smokers (Bell et al., 1994).

The data on the relative distribution of air pollutants indoors relative to outdoors is complicated by the influence of poor air quality days (when AQI values are 50 or greater). Given that levels of ozone, particles, NO<sub>2</sub> and SO<sub>2</sub> are elevated during smog alerts, it is possible that especially on these days, levels are significantly higher outdoors than in many indoor environments. Further research is required, however, to test this hypothesis.

Table 3 provides a simple overview of which pollutants tend to be lowest indoors, based on the studies summarized in the previous two sections. The primary studies on which this comparison is based do not distinguish between days of elevated outdoor pollution, such as when smog alert conditions are reached, and times of lower outdoor pollution levels.

**Table 3. Comparison of Air Pollution Levels Indoors versus Outdoors**

Pollutant	Where Pollutant Levels Tend to Be Lower		
	Indoors <sup>(a)</sup>	Outdoors	Both About Same
Sulphur dioxide	X		
Ozone	X		
Nitrogen dioxide <sup>(b)</sup>			X
CO		X	
Particles (PM <sub>2.5</sub> )	X		
Trace metals	X		
Benzene	X		
VOCs		X	

An "X" indicates that a greater number of studies showed the pollutant level was lower in this environment.

- (a) Based on homes of non-smokers.
- (b) Nitrogen dioxide levels tend to be similar indoors and outdoors in homes without indoor sources such as gas appliances, kerosene heaters or wood stoves. However, in homes where there is combustion of fossil fuels (such as from cooking and space heating), indoor levels tend to be higher.

### Comparison of Pollution Levels with Traffic Density

No recent studies were available that measured pollutant levels in relation to traffic density in Toronto. Data will soon be available from a dense NO<sub>2</sub> monitoring network established in the fall of 2002 for the purpose of modelling exposure to traffic-related pollution in relation to land use (Jerrett, pers. comm., 2003). A pilot study in Montreal revealed a strong inverse relationship between NO<sub>2</sub> levels and distance from an expressway (Gilbert et al., in press).

A previous study by Toronto Department of Public Health (1993) does provide good evidence that CO and NO<sub>2</sub> levels vary based on traffic levels. Table 4 indicates that average hourly CO and NO<sub>2</sub> concentrations are much lower in low traffic areas (such as beside a residential street) compared with high traffic areas (such as beside main streets and major arterial roads). In contrast, the concentration of ozone is lowest in high traffic areas, due to the quenching effect of the large amounts of nitric oxide (NO) emitted directly from vehicles that reduce ozone levels.

**Table 4. Traffic Density versus Pollutant Level**

Parameter	Site 1	Site 2	Site 3
Road Type	Residential	Main street	Major Arterial
Traffic density	Low	Medium	High
Vehicle count per day	2,000	30,000	70,000
Carbon monoxide (mean hourly in ppb)	630	720	930
Nitrogen dioxide (mean hourly in ppm)	23	32	41
Ozone (mean hourly in ppb)	37	26	24

Source: Adapted from Toronto Department of Public Health, 1993.

### Awareness of Smog Alert Warning System

Toronto Public Health participated in a survey of 1,000 Toronto residents conducted by the Ontario Clean Air Alliance in December 2001 for the Toronto Atmospheric Fund. The survey yielded information on a wide variety of air quality concerns, including the provincial Air Quality Index (AQI) and smog alert response. About 46% of those interviewed were unaware that the Ministry of Environment makes information on air quality available to the media and

public through its AQI notification system. Among those aware of the AQI, 12% paid attention on an almost daily basis and 17% paid attention all the time.

More than 90% of those interviewed were aware of smog alerts during the previous summer. Of those people aware of smog alerts, 42% said they avoided strenuous physical activity outdoors on almost all smog alerts, 13% did so on at least half the alert days, and 18% avoided strenuous activity on only a few alert days. Of those aware of smog alerts, 26% reported that they never avoided strenuous activity outdoors on smog alert days (Ontario Clean Air Alliance, 2001).

## STUDY METHODOLOGY

This study involved a reanalysis of existing hourly air pollution data to determine how pollutant levels for NO<sub>2</sub>, CO, PM<sub>2.5</sub>, O<sub>3</sub> and SO<sub>2</sub> varied from hour to hour throughout each 24-hour day.

This analysis was based on data collected from NAPS (National Air Pollution Surveillance) monitoring sites operated by the Ontario Ministry of Environment in Toronto. The monitoring stations were Evans & Arnold (NAPS Station ID 60403), Lawrence and Kennedy (60410), Elmcrest Road (60413) and one station in central Toronto (College Street: 1974 – 1981; Breadalbane Street: 1981 – 1990; Bay and Wellesley: 1990 – 2000). An initial analysis was conducted on all available hourly pollutant levels. SO<sub>2</sub>, CO and O<sub>3</sub> data were available from 1974 to 2000, NO<sub>2</sub> data from 1980 to 2000, PM<sub>10</sub> data from 1996 to 2000, and PM<sub>2.5</sub> from 1997 to 2000. Hourly mean values were calculated for each hour of the day, based on the full data set.

To reduce variability in hourly means attributable to changes in pollution emissions since 1974, a more focused analysis was done using data collected between 1997 and 2000. Hourly mean values were calculated for summer (April to September) and winter (October to March). Hourly mean values of all pollutants were also calculated for those days on which the AQI was less than 50, and those on which it was 50 or greater (i.e. days when air quality was ‘poor’). The ‘poor’ air quality designation (when AQI was greater or equal than 50) was based on one or more pollutants reaching or exceeding the following levels: NO<sub>2</sub> – 260 ppb; O<sub>3</sub> – 81 ppb; SO<sub>2</sub> – 350 ppb; CO – 31 ppm; and PM<sub>2.5</sub> – 46 ug/m<sup>3</sup> (based on 3-hour running mean). These breakpoints are those in use by the Ontario Ministry of the Environment.

## RESULTS

Table 5 shows the dates (marked with an asterisk) during 1997 through 2000 when the AQI in Toronto was 50 or greater, based on the AQI system in place at that time, and which did not include PM<sub>2.5</sub>. Table 5 also shows the dates identified through the analysis conducted in this study when the AQI would have reached a value of 50 or greater, had the OMOE's current AQI classification scheme (which includes PM<sub>2.5</sub>) been in effect at that time. Year 2000 had an unusually cold and rainy summer with few smog advisory days. It is noteworthy that with the addition of PM<sub>2.5</sub> to the AQI, days when air quality is 'poor' (i.e. days when AQI is 50 or greater) are seen to occur almost year round, from March to December. However, the summer months continue to be the period when poor air quality days are most frequent. With the OMOE's previous AQI classification scheme (that did not include PM<sub>2.5</sub>), poor air quality days occurred only between May and September.

**Table 5: Days of 'Poor' Air Quality with Inclusion of PM<sub>2.5</sub> into the AQI**

1997	1998	1999	2000
June 25*	May 15	May 30	March 8*
June 29	May 16	May 31*	May 31*
June 30	May 18*	June 6*	June 10
July 1	May 19*	June 7	July 26
July 2*	June 21	June 12	September 20
July 12	July 3	June 23	
July 13	July 8*	June 26	
July 14	July 9*	July 14	
August 9	July 13	July 15	
August 10*	July 14	July 16	
August 27*	July 15	July 22	
September 17*	July 16*	September 3	
	July 19*	November 10*	
	August 8	December 9*	
	August 23*		
	September 20*		
	September 21*		
<b>12 days</b>	<b>17 days</b>	<b>14 days</b>	<b>5 days</b>

\* Indicates the additional days that would have had an AQI of 50 or greater had the AQI system included PM<sub>2.5</sub> at that time.

Table 6 summarizes the seasonal variation in daily (24-hour) mean pollutant levels. Ozone and particle (PM<sub>10</sub> and PM<sub>2.5</sub>) levels were higher in the summer than winter. SO<sub>2</sub>, CO and NO<sub>2</sub> levels were higher in the winter than summer.

**Table 6: Seasonal Variation in Daily Mean Pollutant Levels (1997-2000)**

Pollutant	Units	Winter mean (± s.d.)	Summer mean (± s.d.)
SO <sub>2</sub>	ppb	5.1 (0.5)	4.3 (0.6)
O <sub>3</sub>	ppb	13.3 (3.5)	25.2 (9.7)
NO <sub>2</sub>	ppb	27.4 (3.1)	25.3 (4.3)
CO	ppm	1.2 (0.1)	1.1 (0.1)
PM <sub>2.5</sub>	ug/m <sup>3</sup>	8.4 (1.0)	12.0 (0.9)
PM <sub>10</sub>	ug/m <sup>3</sup>	18.5 (3.1)	22.5 (2.3)

s.d. – one standard deviation

Table 7 summarizes the mean 24-hour pollutant levels for smog alert days (AQI greater than or equal to 50) and non-alert days (AQI less than 50). With the exception of CO, mean daily pollutant levels were much higher on smog alert days than non-alert days.

**Table 7: Mean Pollutant Levels: AQI Greater than 50 versus Less than 50 (1997-2000)**

Pollutant	Units	AQI 50 or Greater mean (± s.d.)	AQI Less Than 50 mean (± s.d.)
SO <sub>2</sub>	ppb	7.0 (1.8)	4.7 (0.5)
O <sub>3</sub>	ppb	40.5 (19.1)	18.6 (6.0)
NO <sub>2</sub>	ppb	32.9 (6.7)	26.1 (3.4)
CO	ppm	1.1 (0.1)	1.2 (0.1)
PM <sub>2.5</sub>	ug/m <sup>3</sup>	29.0 (2.1)	9.7 (0.8)
PM <sub>10</sub>	ug/m <sup>3</sup>	43.1 (4.7)	19.7 (2.5)

s.d. – one standard deviation

Figure 2 shows the diurnal fluctuation in hourly pollutant levels, with the horizontal lines showing 24-hour (daily) mean levels. The hourly fluctuation in pollutant levels over the recent four-year period (1997-2000) was quite similar to the pattern seen for the full data set from 1974 to 2000. It is notable that each of the five pollutants (SO<sub>2</sub>, CO, NO<sub>2</sub>, O<sub>3</sub> and particles) had a different distribution in hourly values, with particles showing the least variation. CO and NO<sub>2</sub> showed the closest association with traffic rush hour, whereas ozone levels peaked during the afternoon and were at their lowest during morning rush hour. SO<sub>2</sub> peaked just after mid-day. Another notable feature is that, except for CO, all hourly mean pollutant levels on days when AQI was less than 50, were below their respective 24-hour mean pollutant level on ‘poor’ air quality days.

**Figure 2: Diurnal Fluctuation in Hourly Pollutant Levels**

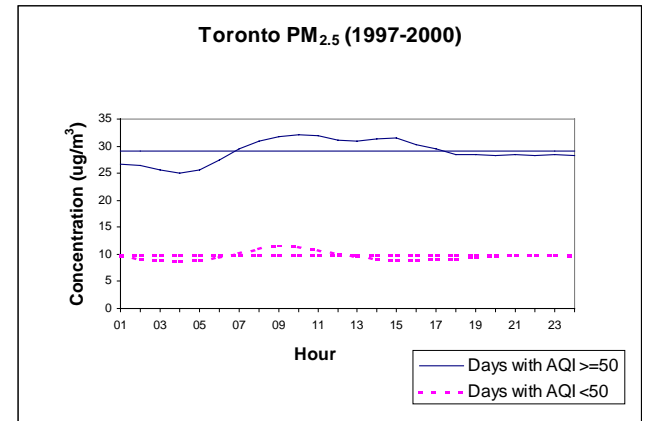
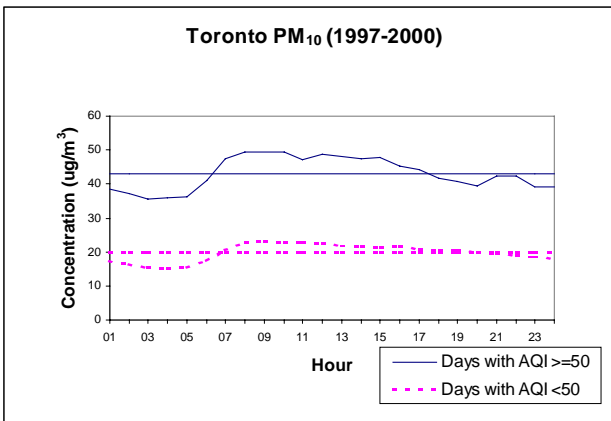
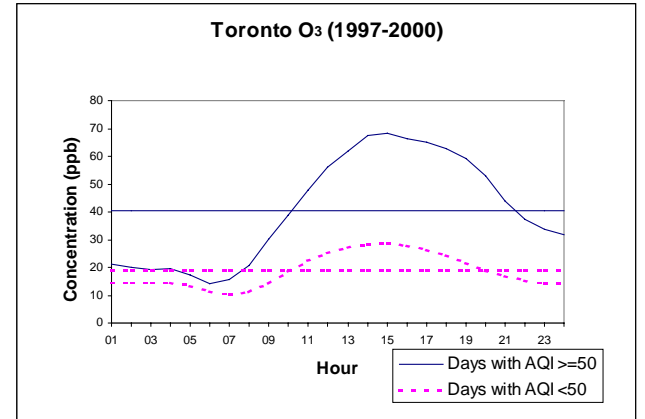
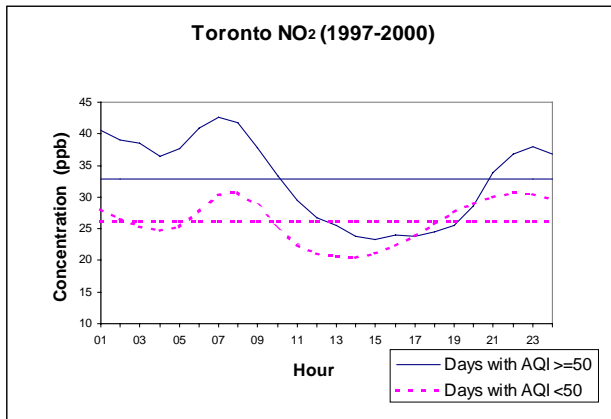
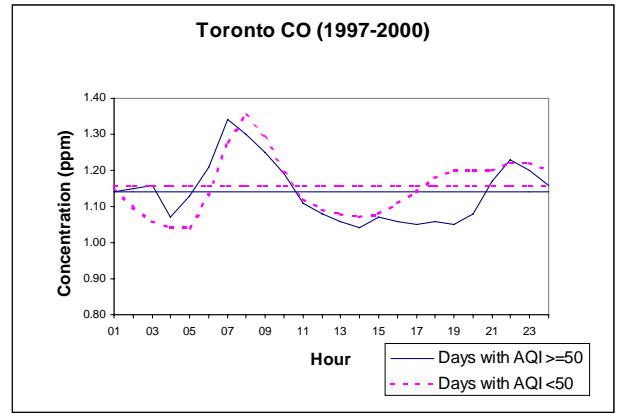
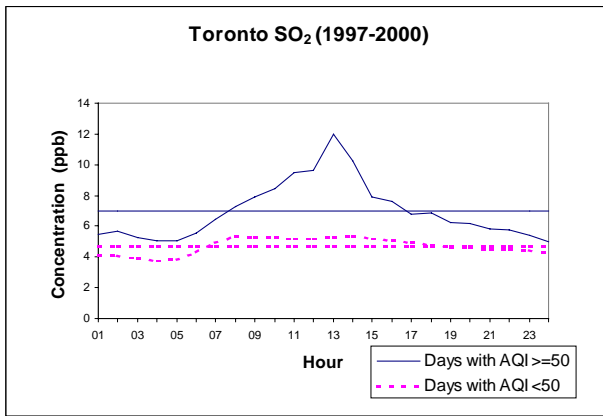


Table 8 indicates the times of the day when pollutant levels are lowest, based on when levels are below the 24-hour daily mean. This pattern is observed in both summer and winter seasons, and on days with AQI values greater and less than 50. In general, all pollutant levels are consistently lowest very early in the morning and late in the evening.

Nitrogen dioxide and carbon monoxide levels are low before 6 a.m. and typically peak by 8 a.m., coinciding with morning rush hour. However, according to the literature, these two pollutants are also much lower in residential areas compared with high traffic areas (see Table 4), so the best way to reduce exposure to them is to avoid vigorous exercise along major arterial roads and highways.

It is notable that, when averaged over many days, there is no pronounced diurnal fluctuation in particle levels, especially for PM<sub>2.5</sub>. Perhaps the relatively consistent concentrations are due to the nature of these tiny particles, which can remain suspended in the air for long periods of time. Figure 2 illustrates that PM<sub>10</sub> and PM<sub>2.5</sub> levels tend to be especially high all day on poor air quality days. The data suggest that the best way to minimize exposure to PM<sub>10</sub> and PM<sub>2.5</sub> is to avoid vigorous outdoor exercise on poor air quality days and that scheduling exercise activities for early morning or evening provides only modest additional benefit.

**Table 8: Times of Day Pollutant Levels Less than Daily Average**

Pollutant	Times of Day Pollutant Level Less Than Daily Average
SO <sub>2</sub>	Before 7 a.m. After 6 p.m.
O <sub>3</sub>	Before 10 a.m. After 8 p.m.
NO <sub>2</sub>	Before 6 a.m. Between 10 a.m. and 7 p.m.
CO	Before 6 a.m. After 5 p.m.
PM <sub>2.5</sub>	Before 7 a.m. After 7p.m.

## DISCUSSION

There is a need to caution everyone, and especially sensitive subpopulations (including seniors, those with asthma, chronic bronchitis, chronic obstructive pulmonary disease and heart problems) to moderate their physical activity outdoors on smog advisory (alert) days and poor air quality days when the AQI reaches or exceeds 50. Given that many smog-related pollutants tend to be higher outdoors than inside homes (of non-smokers), and that this difference may be even more extreme on smog alert days, it is reasonable to encourage the public to consider exercising indoors (in smoke-free environments) if feasible on these days.

There is no compelling evidence to date that healthy adults and children need to limit outdoor physical activity on days when the AQI is below 50. However, research in this area is very limited. There is a need to assess the relationship between outdoor physical activity at differing pollution levels and possible adverse health effects. In the meantime, given that many pollutants (such as ozone and respirable particles) show no evidence of a threshold concentration below which there is no adverse effect (Vedal et al., 2003), even healthy people may wish to plan more vigorous exercise (such as jogging and running) for times of the day when air pollution levels are the lowest, whether or not an air quality advisory is in effect.

During smog alert episodes that last for more than a day, pollutants such as ozone, particles, NO<sub>2</sub> and SO<sub>2</sub> are especially elevated, and may remain elevated throughout much of the day and night. However, on days when the AQI is below 50, pollution levels in Toronto are lowest in low-traffic areas (such as along residential streets rather than main arterial roads), *and* before 7 a.m. and after 8 p.m. These are the conditions under which exposure to both long-range pollutants (such as ozone and PM<sub>2.5</sub>) and locally derived pollutants (such as NO<sub>2</sub> and CO) can be minimized. By planning one's routine running and jogging programs to occur in residential areas and parks (where traffic density is low), one can minimize exposure to vehicle-related pollutants, such as NO<sub>2</sub>, CO, benzene, 1,3-butadiene and PAHs.

People who shift their running or jogging routines to early morning or evening need to consider other issues such as personal safety. For example, it is best to exercise with a partner and to do so in well-illuminated areas. Given the recent concern about the transmission of West Nile Virus (WNV) from infected mosquitoes, and given that mosquito biting activity is greatest in the early morning and evening, it is advisable to avoid areas where mosquitoes are prevalent and use personal protection measures such as wearing mosquito repellent, pants and long-sleeved clothing.

For much of the population, it is not easy to undertake physical activity outdoors at times when air pollution levels are lowest. This is especially true for people who cycle to work or school or for children and adults engaged in daytime sports activities. While everyone should be advised to avoid vigorous physical activity on smog advisory days, on other days of the year individuals can calibrate their own sensitivity based on their experience. Individuals can observe any symptoms (such as coughing, wheezing, chest tightness, pain with breathing deeply, and difficulty breathing) under various air quality conditions as reported through the AQI readings. Individuals should be advised to reduce the intensity of their outdoor activity or replace it with indoor exercise (in a smoke-free environment) at those AQI levels that trigger individual symptoms.

Another factor to consider is how individuals respond to differing air quality conditions and high summertime temperatures. Many summertime smog advisories in Toronto coincide with the Medical Officer of Health's issuance of an extreme heat warning. During these high pollution and high heat episodes, it is especially important to moderate physical activity levels outdoors. Other precautions to take during high heat days are to drink plenty of fluids, wear loose-fitting clothing to allow cooling through evaporation of sweat, and take many rest breaks, preferably in the shade or an air conditioned area.

Evidence is lacking on the relative health benefit of outdoor physical activity when pollution levels are elevated, compared with the health benefit of avoiding increased intake of air pollutants at the expense of reduced physical activity. More research is required in this area. Better evidence is also required on whether relocating vigorous physical activity to interior environments, such as school gymnasiums, and indoor recreational and sports facilities, results in meaningful reductions in personal exposures to air pollutants during poor air quality days.

Another area for further research is to assess whether modifications in outdoor physical activity patterns can mitigate possible adverse health effects, especially when pollution levels approach or exceed smog-alert conditions. For example, it would be useful to determine whether there is any benefit in recommending less strenuous activity (light or moderate effort versus vigorous effort), reduced length of exercise period, or intermittent exercise with more rest periods in between.

This information is especially important in guiding children and adults with pre-existing cardiac or respiratory conditions on health protective actions to take when air quality deteriorates. The population at risk is large. For example, about 48,000 Toronto residents were admitted to hospital in 1998 with cardiac and respiratory illnesses (Toronto Public Health, 2001a). These people are likely especially vulnerable to the adverse effects of air pollution.

There is also a need for evidence-based guidance for children, adults and athletes with asthma regarding vigorous outdoor exercise on days with elevated air pollution. Asthma is an increasingly common respiratory problem, such that 2.2 million Canadians have been diagnosed with asthma at some time in their lives. Currently about 12% of children (0 to 19) and 6.3% of adults in Canada have asthma (Toronto Public Health, 2001a). The public looks to its public health agencies for guidance as to appropriate activity levels outdoors for asthmatics as air pollution levels increase.

## CONCLUSION

Air pollution continues to pose a significant health risk to the Toronto population. Overall, most smog-related air pollution has not improved appreciably in the last two decades in Toronto. With climate change, the number of smog alert and poor air quality days may increase. Even at pollution levels below those triggering smog advisories, many people, and especially those with cardiac and respiratory conditions, are vulnerable to adverse health effects. These effects may be exacerbated with vigorous physical activity outdoors, in large part because of the increased exposure to air pollutants with increased inhalation rates during vigorous exercise. This is an unfortunate situation because regular physical activity has a profound and positive influence on people's health.

Although it is prudent for everyone to pay attention to up-to-date AQI reporting by media outlets, or to connect directly (via telephone or website) to the Ontario Ministry of the Environment's AQI information service, it is unlikely that everyone will do so. Whereas people in Toronto have a high awareness of smog alert days (more than 90% are aware), awareness of the AQI notification system is much poorer, and only a small fraction of people pay attention to the AQI on a daily basis. Vulnerable individuals may be more inclined to monitor the AQI values on a regular basis and adjust their activity levels accordingly, however, healthy people might not.

There is a need to encourage more Toronto residents to monitor AQI values, especially if they are at-risk or have responsibility for vulnerable individuals. In addition, it may be beneficial for healthy active people to shift their routine outdoor fitness activities, where reasonable, to times of the day and locations where pollution levels are lowest, consistent with where and when AQI values would be expected to be lowest. However, even healthy people should moderate their physical activity outdoors at all times of the day when smog advisories are in effect.

It is not possible or reasonable for much of the population, especially children who are active in daytime sports events at schools, day cares, recreational facilities and summer camps, to shift their periods or locations of vigorous activity. Consequently, there is a need for more research to guide the development of health protective advice that takes into account the health benefit of regular exercise (even during times of elevated air pollution) and identifies possible modifications in activity patterns to lessen health risk from air pollution. There is also a need for more research on how indoor pollution levels in the home, at child care facilities, schools, and sports and recreational centres compare with outdoor levels, especially during smog alerts, so that staff and

parents can develop sound policies regarding physical activity when ambient air quality is poor.

Based on our analysis of air pollution levels in Toronto, and review of exposure assessment and health effects studies by other investigators, we offer the following guidance to Toronto residents for minimizing exposure to air pollutants while maximizing physical activity:

***On Smog Alert Days and When the AQI is 50 or Higher:***

- Moderate physical activity outdoors on smog alert and poor air quality days, even if you are healthy. Ways of moderating activity are to shift from vigorous activity levels to moderate or light activity levels, reducing the duration of activity and introducing more rest breaks. Drink plenty of water before, during and after exercise.
- For all people, but especially those with heart or breathing problems (including asthma), it is important they monitor any symptoms they experience with different activity levels and as the air quality index (AQI) increases. Examples of symptoms to look out for include coughing, wheezing, chest tightness, pain with breathing deeply, and difficulty breathing. Anyone experiencing symptoms should reduce their level of activity.
- On smog alert days, consider exercising indoors in a smoke-free environment, and if available, one that is air-conditioned

***On Non-Alert Days (When the AQI is Less than 50):***

- Continue to monitor any symptoms experienced with different activity levels and as the air quality index (AQI) increases. Reduce activity level outdoors when AQI values are above those known to trigger each individual's symptoms.
- If possible, schedule routine vigorous exercise, such as running and jogging, for early in the morning (before 7 a.m.) and in low traffic areas (such as residential neighbourhoods and parks)

Most importantly, however, it is essential that persons involved in health promotion emphasize the health benefit of physical activity in ensuring well-being, including the prevention of disease. Routine physical activity on a year-round basis is to be encouraged, while alerting the public to ways of moderating vigorous physical activity outdoors on those days when smog alerts occur.

While there is a need to protect that segment of the population already engaged in routine vigorous activity from air pollution during smog alerts, it is critical to recognize the health benefit of more modest measures to increase physical activity in those persons who tend to be sedentary. There is a need to increase awareness that introducing more light activity (such as with slow pace walking, easy gardening, stretching) and moderate activity (such as with brisk walking, bicycling, raking leaves) to persons who are generally inactive is very beneficial to improving their health. To date, there appears to be no evidence that light or moderate physical activity during smog alert conditions poses a health risk to people without other underlying medical conditions. However, there is some evidence in the literature that prolonged vigorous activity when air quality is poor can pose a health risk, especially to those persons with pre-existing respiratory conditions. More research is required in this area.

In the long term, it is important to ensure that barriers to physical activity, such as limited physical education opportunities in schools, access to recreational or sports facilities, and availability of green space are addressed in a comprehensive way to achieve public health goals. Accelerated action on improving air quality is of paramount important for many reasons, not least of which is to ensure that poor air quality does not become another barrier to enhancing physical activity.

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