CRITIQUE

Health Review Committee

Research Report 148, *Impact of Improved Air Quality During the 1996 Summer Olympic Games in Atlanta on Multiple Cardiovascular and Respiratory Outcomes,* J.L. Peel et al.

INTRODUCTION

In recent decades, there have been substantial reductions in ambient concentrations of most combustion-related pollutants in the United States, Europe, and elsewhere. Because the cost of pollution-control technologies and enforcement of regulations to achieve increasingly lower concentrations of air pollutants can be relatively high, it is important to determine whether regulations and other actions taken to improve air quality are effective in reducing emissions, reducing the public's exposure to air pollutants, and ultimately in achieving the intended improvements in public health. So far, the number of studies pursuing such *accountability* research has been limited. Traffic is an important source of air pollutants to which a large segment of the population is exposed, especially in urban areas. Many locations around the world are implementing actions to reduce traffic congestion. Although such measures may not be specifically designed to reduce air pollution concentrations, it is possible that they may lead to improved air quality. There is increasing interest in evaluating whether this is the case.

HEI's Accountability Research program was initiated to support research that would evaluate the effects of actions taken to improve air quality (for more information on the program, see the Preface to this report). As part of the Fall 2004 Research Agenda, HEI issued Request for Applications (RFA*) 04-4, "Measuring the Health Impact of Actions Taken to Improve Air Quality." In response to the RFA, Dr. Jennifer Peel of the Department of Environmental and Radiological Health Sciences at Colorado State University in Fort Collins, Colorado, and colleagues submitted a proposal to study the effects of a short-term, temporary intervention designed to reduce traffic congestion during the 1996 Summer Olympic Games in Atlanta, Georgia. Actions taken by the city of Atlanta included (1) promoting the use of and providing increased availability of public transportation; (2) providing a system to give travelers up-to-date information on traffic congestion, alternative routes, and directions to Olympic Village parking; and (3) encouraging businesses to provide telecommuting options and alternative work hours for their employees or to encourage their employees to use vacation time during the Olympic Games.

A previous study of the Atlanta Olympic Games traffic intervention had shown a decrease in acute care visits for pediatric asthma and a concomitant decrease in concentrations of ozone (O_3), particulate matter ≤ 10 µm in aerodynamic diameter (PM_{10}), and carbon monoxide (CO) during the Olympic Games compared with the weeks before and after (Friedman et al. 2001). Peel and colleagues proposed further analyses using a large database on emergency department (ED) visits collected as part of the Study of Particles and Health in Atlanta (SOPHIA). They proposed to assess additional disease categories in adults and elderly individuals as well as in children, evaluate a wider time window surrounding the Olympic Games period (comparing 1996 with the years before and after the Olympic Games), include a larger geographic area in their analyses, and examine the potential influence of meteorologic conditions on O_3 concentrations. The HEI Research Committee thought that these additional analyses would enhance our understanding of the possible effects of the intervention on health outcomes and recommended the study for funding.

SCIENTIFIC BACKGROUND

There is a large body of epidemiologic evidence showing that exposure to increased concentrations of ambient air pollutants, in particular O_3 and PM, is associated with increased respiratory and cardiovascular mortality and with increased hospital admissions. Such effects have been demonstrated in large cohort studies that compared populations with differing long-term exposures to air pollutants (Pope et al. 2002; Jerrett et al. 2009; Krewski et al. 2009), as well as in time-series analyses that compared hospitalizations or

Dr. Peel's 1-year study, "Impact of Improved Air Quality During the 1996 Atlanta Olympic Games on Multiple Cardiorespiratory Outcomes," began in March 2006. Total expenditures were $62,000. The draft Investigators' Report from Peel and colleagues was received for review in January 2008. A revised report, received in February 2009, was accepted for publication in March 2009. During the review process, the HEI Health Review Committee and the investigators had the opportunity to exchange comments and to clarify issues in both the Investigators' Report and in the Review Committee's Critique.

* A list of abbreviations and other terms appears at the end of the Investigators' Report.

mortality on days with high pollutant concentrations with those on days with low pollutant concentrations (Samet et al. 2000; Bell et al. 2004; Katsouyanni et al. 2009). The associations between O_3 or PM concentrations and health outcomes are consistent across different continents (Schwela 2000; Anderson et al. 2004).

Although there has been substantial progress in reducing emissions from the transportation sector, those emissions remain a major contributor to urban air pollution. With a large segment of the population living in close proximity to traffic sources, exposure to traffic-related air pollutants is an important public health concern. According to HEI's recent review, there is sufficient evidence to infer a causal association between exposure to traffic-related pollution and asthma exacerbation; studies that have evaluated the relationship between the distance from residences or schools to busy roads and health outcomes (e.g., respiratory symptoms, asthma incidence, pulmonary function, or mortality) suggest a causal relationship (HEI Panel on the Health Effects of Traffic-Related Air Pollution 2010).

Because of the substantial public health impacts, many countries have implemented regulations to reduce general exposure to traffic-related air pollution. Examples are regulations aimed at reducing sulfur in fuel (e.g., in Hong Kong; see Hedley et al. 2002), restricting older vehicles with relatively high emission levels from entering downtown areas — as is being done in an increasing number of cities in Europe and elsewhere — or targeting traffic congestion. Measures to reduce congestion in major urban areas include charging a fee for vehicles to enter the area (e.g., in London, Singapore, and Stockholm; see Hugosson et al. 2006; Kelly et al. 2010), banning entry of nonresidents' vehicles (in Rome), and imposing restrictions on residents as to when they may use their vehicles (in Mexico City, Athens, and Budapest). Specific actions may also be targeted at temporarily reducing traffic congestion or improving air quality in association with a major event, such as the Olympic Games (e.g., Friedman et al. 2001; Wang et al. 2008).

Several recent studies assessed whether such measures to reduce traffic have improved air quality in the surrounding areas. For example, Dijkema and colleagues (2008) showed that lowering the maximum speed limit on a section of the urban ring highway in Amsterdam, the Netherlands, significantly reduced PM concentrations in the immediate vicinity of the highway. Substantial, unplanned reductions in traffic in Haifa, Israel led to significant reductions in concentrations of PM, hydrocarbons, and nitrogen dioxide (NO_2), but not in O_3 (Yuval et al 2008). Kelly and colleagues studied the London Congestion Charging Scheme (CCS) that was implemented to reduce the number of vehicles entering central London during business hours (Atkinson et al. 2009; Kelly et al. 2010). Using a temporal-spatial analysis, this group found no significant changes in air pollutant concentrations at a roadside monitor in the CCS zone, but they did observe decreased concentrations of nitrogen monoxide and increased concentrations of nitrogen oxides (NO_x) and O_3 at three nonroadside monitors. These changes could not be attributed to the CCS because there were other simultaneous changes in traffic and emissions; it was not possible to empirically evaluate changes in health outcomes because the area covered by the CCS was small (Kelly et al. 2010). However, the group also calculated — using modeled air quality and health effects estimates from other studies — that the CCS would have a positive effect on life expectancy (Tonne et al. 2008). The congestion charging trial in Stockholm was effective in improving traffic flow throughout the city and also provided some air quality benefits (Hugosson et al. 2006). A recent study showed that such schemes may provide additional health benefits because people may choose alternative transportation options that involve physical activity (Bergman et al. 2010). Similar congestion charging schemes are being considered in other cities (e.g., New York City) and may provide opportunities for future research.

The intervention to reduce traffic congestion in Atlanta during the 1996 Summer Olympic Games provided an opportunity to study the impact on air quality and public health of a short-term, temporary intervention focused on traffic congestion. Friedman and colleagues (2001) evaluated acute care visits and hospitalizations for pediatric asthma during the 17 days of the Summer Olympic Games, compared with 4-week periods before and after the Olympic Games. They found significant declines in the number of pediatric asthma acute care events during the Olympic Games based on data from Georgia Medicaid claims. In addition, they observed concurrent reductions in peak weekday morning traffic counts and in daily peak O_3 concentrations that were suggestive of an association between the traffic intervention and the reduction in asthma events. However, the analyses had limited statistical power because of the short study period and because the investigators did not appear to correct for seasonal trends in air pollutant concentrations or health outcomes. Thus, Peel and colleagues proposed to reexamine the impact of improved air quality during the 1996 Olympic Games on multiple respiratory and cardiovascular outcomes and to analyze the effect that seasonal trends and meteorologic conditions may have had on air quality.

SPECIFIC AIMS

The investigators pursued the following specific aims:

1. Examine ambient air pollutant concentrations during the Olympic Games and surrounding baseline periods in the Atlanta area and throughout the Southeastern United States;
2. Examine traffic counts in Atlanta during the Olympic Games and surrounding baseline periods;
3. Evaluate ED usage patterns and characteristics during the Olympic and baseline periods; and
4. Compare results obtained for the Olympic period with results for the baseline periods, adjusting for temporal trends and meteorologic conditions.

The investigators used ED data for 1995 though 2004 that had been collected for more than 30 hospitals in Atlanta as part of the SOPHIA project, which examined the associations between daily air quality and daily ED visits for cardiovascular and respiratory outcomes (e.g., Metzger et al. 2004; Peel et al. 2005).

An additional original aim of the current study was to evaluate ventricular arrhythmias in patients with an implantable cardioverter defibrillator, which continuously records the heart rhythms of patients and stores information on the date and time of each arrhythmic event. Data from two cardiac electrophysiology clinics in Atlanta were available during the entire study period. Although 884 subjects were followed, there were only six ventricular events during the Olympic period. Because this small sample size precluded a meaningful interpretation of the results, those data were not included in the Investigators' Report.

METHODS

AMBIENT AIR QUALITY

Daily ambient air quality data for five central counties within the Atlanta area were obtained from the U.S. Environmental Protection Agency's (U.S. EPA's) Air Quality System and from the Georgia Department of Natural Resources. The fixed monitors measured PM_{10} and the gaseous pollutants CO, O_3, NO_2, NO_x, and sulfur dioxide (SO_2). There were two monitoring sites for each of the pollutants except for PM_{10} mass, which was measured at only one site. Meteorologic data were obtained from the National Climatic Data Center and included temperature, dew point temperature, amount of sunshine, and precipitation for the Atlanta area.

To evaluate whether changes in air quality were restricted to Atlanta or were more regional in nature, the investigators obtained air quality data from more rural sites in Georgia as well as from six urban areas in the Southeastern United States located between 120 and 250 miles from Atlanta (Birmingham, AL; Tallahassee, FL; Charlotte, NC; Chattanooga, Knoxville, and Nashville, TN).

TRAFFIC COUNTS

Daily 1-hour maximum for the morning (4–10 AM) and total daily traffic counts were calculated for weekdays from data collected by the Georgia Department of Transportation, which in 1996 conducted hourly traffic counts at 18 sites within the 5-county area studied.

HEALTH OUTCOMES

Data on ED visits were obtained for 12 hospitals in the 5-county area that had data for the Olympic Games period (July 19, 1996, through August 4, 1996); 2 of the 12 were pediatric hospitals that were included in the analyses by Friedman and colleagues (2001). More than 25,000 total ED visits from Atlanta residents were included; visits from nonresidents were excluded from the analyses (such visits were slightly more frequent during the Olympic Games). Hospital discharge data were obtained for the years 1995 through 2004 and included specific *International Classification of Diseases,* 9th Revision diagnostic codes and patient age. Respiratory case groups of interest included asthma, chronic obstructive pulmonary disease (COPD), upper respiratory infection, pneumonia, and all four respiratory case groups combined. Cardiovascular case groups of interest were ischemic heart disease, acute myocardial infarction, cardiac dysrhythmias, congestive heart failure, peripheral and cerebrovascular disease, and all five cardiovascular case groups combined. The finger wounds case group was used as a control because this outcome was not expected to have an association with air pollutant concentrations. The investigators focused on three age groups: pediatric (2–18 years), adult (19–64 years), and older adult ($\geq$ 65 years).

STATISTICAL ANALYSES

The investigators summarized air quality data from monitoring sites within the 5-county area and provided time-series plots for the summer months in 1996 compared with average concentrations in the summer months for all other years (1995 and 1997–2004). Traffic counts for 1996 were averaged for the Olympic and surrounding baseline periods (4 weeks before and 4 weeks after the Olympic Games). The investigators compared mean pollutant concentrations and traffic counts between the Olympic and baseline periods using a time-series approach.

The numbers of daily ED visits were summarized by disease category, age group, race category, payment type, and sex for the Olympic and baseline periods and analyzed using Poisson generalized linear models (GLMs). The 73-day period of interest included the 17 days of the Olympic Games and 28 days immediately before and after the Olympic Games (baseline periods). Primary analyses were performed on ED visits for the 73-day period in 1996 as well as the surrounding years (1995 and 1997–2004; 730 total days). The investigators analyzed ED visits from all 12 hospitals, the 8 hospitals in downtown Atlanta (inside the perimeter highway), the 4 hospitals outside the perimeter highway, and the 2 pediatric hospitals. They separately analyzed ED visits for residents who lived inside the perimeter highway, and for the three age groups. The analyses were adjusted for day-of-week, daily minimum temperature, daily average dew point temperature, day-of-summer, and year.

Secondary analyses were conducted on the short 73-day time series (1996 Olympic and baseline periods only). The investigators analyzed ED visits for all 12 hospitals and for the 2 pediatric hospitals in order to replicate the analyses of Friedman and colleagues (2001). They conducted a number of sensitivity analyses using generalized estimating equations (GEEs) to evaluate the effects of model choices and choices of baseline periods on the estimates.

OVERVIEW OF KEY RESULTS

Peel and colleagues reported that total daily traffic counts on weekdays were not reduced during the Olympic Games period compared with the four weeks before and after. In fact, significant increases were observed at 2 of the 18 sites. However, weekday morning traffic counts (i.e., 1-hour maximum) at most sites were slightly lower during the Olympic Games period. Significant decreases (of up to 20%) in the daily morning traffic counts were observed at 4 sites in Fulton and DeKalb Counties near downtown Atlanta; traffic counts at other sites were lower by 2% to 15%.

Peel and colleagues observed that 8-hour maximum O_3 concentrations in Atlanta were 30% and 22% lower during the Olympic Games period than during the four weeks before and after the Olympic Games, respectively. One-hour maximum O_3 concentrations were also significantly lower during the Olympic Games period. One-hour maximum CO concentrations were also significantly reduced (by ~30%); 1-hour maximum NO_2, and 24-hour average PM_{10} concentrations were reduced to a lesser extent (by 5%–17%), but the changes were not significant. One-hour maximum SO_2 concentrations were not changed. Evaluation of more rural areas of Georgia and other urban areas of the Southeastern United States that were unaffected by the traffic interventions showed that decreased O_3 concentrations were observed regionally and could be attributed to meteorologic conditions in the region. The observed patterns of daily pollutant concentrations during the Olympic Games period in 1996 were similar to those observed during the same weeks in the years before and after the Olympic Games.

In the primary statistical analyses — the 1996 Olympic Games period compared with its baseline periods, adjusted for those same 73-day periods in surrounding years — Peel and colleagues did not observe significant changes in the number of ED visits for the combined respiratory case groups (relative risk [RR] = 1.012; 95% confidence interval [CI] = 0.920–1.113), the combined cardiovascular case groups (0.996; 0.829–1.195), or the individual respiratory or cardiovascular case groups (data for all 12 hospitals and all age groups). The numbers of ED visits for upper respiratory infections and pneumonia were somewhat reduced, but the changes were consistent with chance fluctuations. The only significant change was an increase in the number of ED visits for COPD (1.420; 1.048–1.925).

In the secondary statistical analyses — the 1996 Olympic Games period compared with its baseline periods without adjustment for surrounding years — Peel and colleagues reported a decrease in the number of ED visits for upper respiratory infections for all ages (RR = 0.863; 95% CI = 0.767–0.970) and for the pediatric age group (0.779; 0.632–0.962). They also reported a decrease in the numbers of ED visits for the combined respiratory case groups for all ages (0.901; 0.810–1.002) and for the pediatric age group (0.798; 0.657–0.969). They observed a small decrease in the number of ED visits for pediatric asthma (0.953; 0.650–1.399), similar to that reported by Friedman and colleagues (2001). However, the change was consistent with chance fluctuation, and the investigators reported that the results were sensitive to tighter controls for time trends. They did not observe any changes in ED visits covered by Medicaid for pediatric asthma (1.132; 0.703–1.823) or any of the other health outcomes.

HEI HEALTH REVIEW COMMITTEE EVALUATION

The work by Peel and colleagues has addressed important questions that had remained unanswered by the initial assessment of ED visits for pediatric asthma during the 1996 Summer Olympic Games (Friedman et al. 2001). For

Impact of Improved Air Quality During the 1996 Summer Olympic Games in Atlanta on Multiple Cardiovascular and Respiratory Outcomes

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ABSTRACT

Substantial evidence supports an association between ambient air pollution, especially particulate matter (PM*) and ozone (O_3), and acute cardiovascular and respiratory morbidity. There is increasing interest in accountability research to evaluate whether actions taken to reduce air pollution will result in reduced morbidity. This study capitalized on a unique opportunity to evaluate the impact of a local, short-term intervention effort to reduce traffic in Atlanta during the 1996 Summer Olympic Games (July 19–August 4). Air pollutant concentrations both inside and outside of Atlanta were examined during the Olympic period and surrounding periods. Emergency department (ED) visits were examined to evaluate changes in usage patterns. ED visits for respiratory and cardiovascular conditions were examined in relation to the Olympic period using Poisson time-series analysis with adjustment for time trends and meteorologic conditions.

O_3 concentrations were approximately 30% lower during the Olympic Games compared with the four weeks before and after the Olympic Games (baseline periods); however, we observed similar reductions in O_3 concentrations in several other cities in the Southeastern United States. We observed little or no evidence of reduced ED visits during the Olympic Games; the estimates were sensitive to choice of analytic model and to method of adjusting for temporal trends.

The meteorologic conditions during the Olympic Games, along with the reductions in O_3 observed in various cities not impacted by the Olympic Games, suggest that both meteorologic conditions and reduced traffic may have played a role in the observed reduction in O_3 concentration in Atlanta. Additionally, it is likely that this particular intervention strategy would not be sustainable as a pollution-reduction strategy. This study demonstrates some limitations of conducting retrospective accountability research.

INTRODUCTION

Substantial evidence supports an association between ambient air pollution, particularly PM and O_3, and acute cardiovascular and respiratory morbidity (U.S. Environmental Protection Agency [U.S. EPA] 2004, 2006; Pope and Dockery 2006). The National Research Council (2002) and HEI (2003) have emphasized the need for accountability investigations exploring the potential impacts of reduced air pollution to inform regulatory decisions. However, the number of such investigations remains fairly low. Previous studies have provided limited evidence that reductions in ambient air pollution are related to small reductions in mortality (Pope 1989; Pope et al. 1992, 2007; Clancy et al. 2002; Hedley et al. 2002; Lwebuga-Mukasa et al. 2003; Laden et al. 2006; Dominici et al. 2007), in health care utilization (Friedman et al. 2001; Lwebuga-Mukasa et al. 2003; El-Zein et al. 2007), and in age-related lung function decline (Downs et al. 2007).

This Investigators' Report is one part of Health Effects Institute Research Report 148, which also includes a Critique by the Health Review Committee and an HEI Statement about the research project. Correspondence concerning the Investigators' Report may be addressed to Dr. Jennifer L. Peel, Department of Environmental and Radiological Health Sciences, Colorado State University, 1681 Campus Delivery, Fort Collins, CO 80523-1681.

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* A list of abbreviations and other terms appears at the end of the Investigators' Report.

The 1996 Summer Olympic Games in Atlanta provided a unique context for examining the health impacts of actions taken to reduce traffic volume and congestion and the concurrent reductions in ambient air pollution. For these Olympic Games, various strategies were employed to reduce traffic, especially during the morning and evening rush hours (National Cooperative Highway Research Program [NCHRP] 2001). Friedman and colleagues (2001) reported reduced concentrations of O_3, PM_{10} (PM with an aerodynamic diameter ≤ 10.0 µm), and carbon monoxide (CO) in Atlanta during this period compared with the weeks before and after the Olympic Games. They also reported reduced Medicaid and health maintenance organization (HMO) claims for pediatric asthma during the Olympic Games compared with a baseline period four weeks before and four weeks after the Olympic Games (Medicaid: relative risk [RR] = 0.48, 95% confidence interval [CI] = 0.44–0.86; HMO: RR = 0.58; 95% CI = 0.32–1.06). Results for the other databases, including pediatric ED visits, showed slight reductions but were generally consistent with a null association.

Although the investigation by Friedman and colleagues (2001) was one of the first to examine the impact of an intervention to reduce traffic and has been widely cited as evidence of an intervention that resulted in both reduced air pollution and reduced health care use, there were several potential limitations in its design and analysis. The time series was very short (73 days), and the mean number of daily events (ED visits) was low, potentially leading to instability of the results. The time-series analysis did not control for time trends, which may be important given that July and August typically have low numbers of asthma exacerbations compared with surrounding months (Varner 2001). Also, Friedman and colleagues (2001) investigated the effect of traffic-related air pollution only on ED visits for pediatric asthma. Studies of cardiovascular and respiratory health outcomes for various age ranges may provide further insight into the effects of reduced air pollution on morbidity.

SPECIFIC AIMS

This study was designed to comprehensively assess the impact of the reduced air pollution, observed during the 1996 Summer Olympic Games in Atlanta, on multiple cardiovascular and respiratory outcomes using ED visit data collected from 1993 through 2004 as part of the Study of Particles and Health in Atlanta (SOPHIA). The present study had the following specific aims:

1. Examine ambient air pollutant concentrations during Olympic and baseline periods in the Atlanta area and throughout the Southeastern United States;
2. Examine traffic counts in Atlanta during the Olympic Games period and its baseline periods;
3. Evaluate ED usage patterns and characteristics during Olympic and baseline periods; and
4. Evaluate the relationship of the Olympic period compared with the baseline period, adjusting for temporal trends and meteorologic conditions.

Given the previously published study (Friedman et al. 2001), we hypothesized that O_3 concentrations would be lower during the Olympic Games period compared with the baseline; however, we also hypothesized that we would see a similar pattern throughout the Southeastern United States due to large-scale meteorologic patterns. Also, given the results of the previous study (Friedman et al. 2001), we hypothesized that we would observe reductions in ED visits during the Olympic Games period compared with the baseline periods, particularly for Medicaid visits, but that the observed reduction would be sensitive to adjustment for temporal trends.

METHODS AND STUDY DESIGN

HUMAN STUDIES APPROVAL

This project was approved by the Institutional Review Boards of Colorado State University and Emory University.

STUDY PERIODS

Definitions of the periods used in this report are:

- Olympic period — July 19 through August 4 (17 days) in each of several years as listed below.
  - Olympic Games period (the Olympic period of 1996)
  - 11-year combined Olympic period (the combined Olympic periods of years 1993–2004, excluding 1996)
  - 9-year combined Olympic period (the combined Olympic periods of years 1995–2004, excluding 1996)
- Baseline periods — June 21 through July 18 and August 5 through September 1 ([56 days] four weeks before and four weeks after an Olympic period).
  - Olympic Games baseline periods (the baseline periods of 1996)

   - 11-year combined baseline periods (the combined baseline periods of years 1993–2004, excluding 1996)
   - 9-year combined baseline periods (the combined baseline periods of years 1995–2004, excluding 1996)
- 10-year summer time-series period (June 21–September 1 of years 1995–2004, including 1996).

STUDY LOCATION

Atlanta, the capital of Georgia, is located in the northern part of the state (Figure 1) at an elevation of 1000 feet above sea level. The SOPHIA project collects information on ED visits for the Atlanta metropolitan statistical area (MSA) as defined by the U.S. Census Bureau in 1993, an area that includes the 20 counties surrounding downtown Atlanta. Because the efforts to reduce traffic during the Olympic Games focused mainly on the downtown Atlanta area in which the main Olympic venues were located, we focused on the five central counties, as well as on the area inside the perimeter highway encircling the city of Atlanta (the five counties and perimeter highway are shown in Figure 1). According to the U.S. Census Bureau, the city of Atlanta had a population of 394,000 in the year 1900 and 416,474 in the year 2000. The 5-county area had a population of 2.2 million in 1990 and nearly 3 million in the year 2000.

TRAFFIC INTERVENTION DURING THE OLYMPIC GAMES

Leading up to the Olympic Games, officials launched a publicity campaign aimed primarily at reducing normal daily commuter traffic (morning and evening rush hours) (Georgia Environmental Protection Division [GA EPD] 1996). Efforts to reduce traffic during the 17 days of the

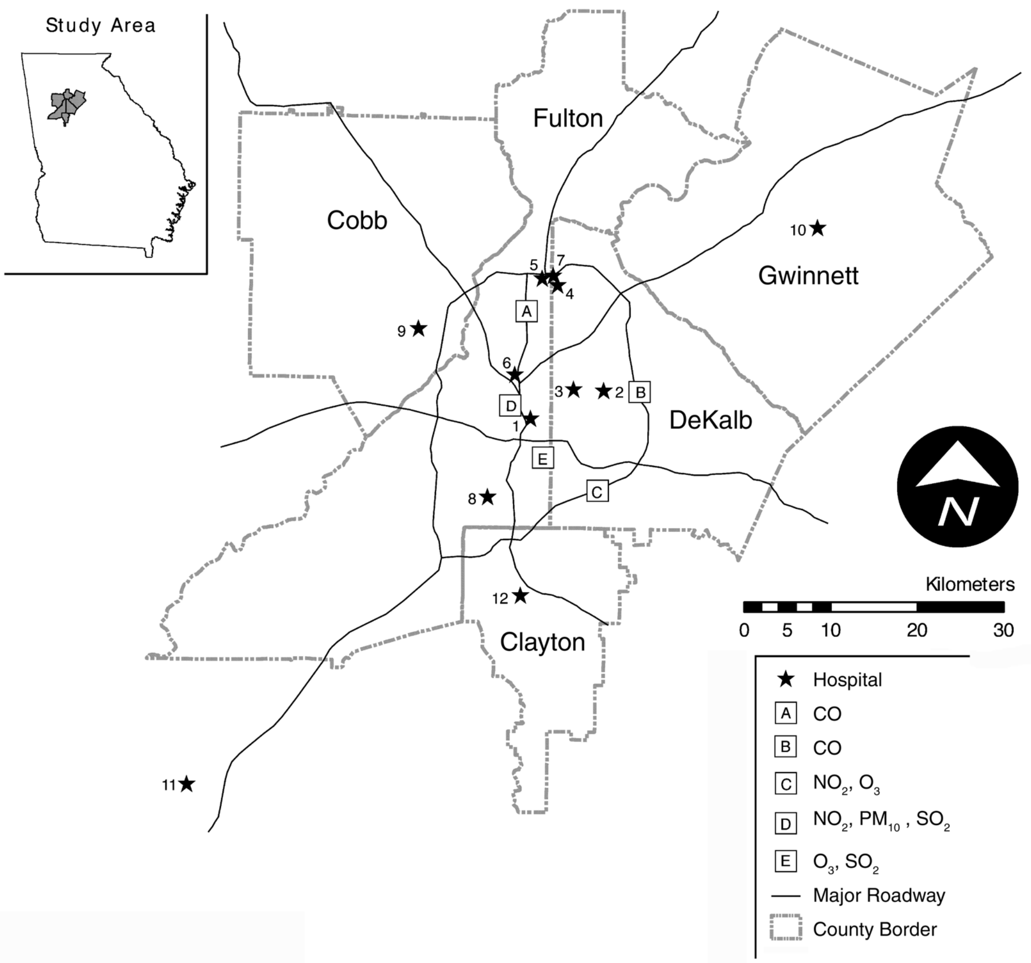

Figure 1. Map showing the five counties of the Atlanta area, the study hospitals at locations 1–12, and locations of the air quality monitor sites (A: Roswell Road, B: DeKalb Tech, C: South DeKalb, D: Georgia Institute of Technology, E: Confederate Avenue). The pediatric hospitals are at locations 3 and 4. Map data source: U.S. Geological Survey National Atlas; Projection: Georgia State Plane West.

STATISTICAL METHODS AND DATA ANALYSIS

Analyses were carried out using SAS statistical software, version 9.1 (SAS Institute, Cary, NC).

AMBIENT AIR POLLUTION DATA

We calculated mean concentrations of the ambient air pollution using measurements from the monitoring sites within the 5-county Atlanta area for the Olympic Games period, for the Olympic Games baseline periods, and for the 11-year combined Olympic period. We calculated similar mean concentrations for pollution monitoring sites outside of the Atlanta area. We compared the mean concentrations between the Olympic and baseline periods using generalized linear models (GLMs). We also calculated mean pollutant concentrations at each site in the 5-county area for the Olympic Games period and its baseline periods, as well as mean concentrations for the 9-year combined Olympic and baseline periods.

TRAFFIC COUNTS

We calculated mean traffic counts during the Olympic Games and the corresponding baseline periods, and then used GLMs to compare the Olympic Games period with its baseline periods.

ED VISITS

We calculated the percentage of Atlanta residents (of the 5-county area) out of the total ED visits during Olympic Games period and its baseline periods. For residents of the 5-county area and for residents inside the perimeter highway, we examined the proportions of ED visits according to age categories, race categories, payment type, and sex, and the percentage of all ED visits coded as respiratory or cardiovascular for the various periods.

In an additional set of analyses, we calculated the mean daily number of ED visits by case group for the Olympic Games period and its baseline periods and for the 9-year combined Olympic and baseline periods.

ED VISIT ANALYSES

To evaluate the referent (baseline) period and our various modeling choices, we performed multiple Poisson time-series analyses using the daily number of ED visits for each case group defined earlier. The primary analyses were performed for ED visits from residents of the 5-county area for the 12 hospitals combined. Secondary analyses included ED visits for: 1) the hospitals inside the perimeter highway (hospitals 1–8); 2) the hospitals outside the perimeter highway (hospitals 9–12); 3) the two pediatric hospitals only (hospitals 3 and 4); 4) residents inside the perimeter highway; and 5) age-specific case groups (pediatric, adult, and older adult).

We also performed several generalized estimating equation (GEE) analyses, similar to the primary GLM analysis (with an autoregressive correlation structure), to evaluate the sensitivity of the results of the primary analysis to the modeling choices.

For all analyses the indicator value for an Olympic period was 1; for baseline periods the indicator value was 0.

Primary Analyses

The primary analyses used Poisson GLMs (McCullagh and Nelder 1989) of the daily number of ED visits for the defined case groups during the Olympic and baseline periods of years 1995 through 2004, including the Olympic year. All models included terms for day-of-week, daily minimum temperature (lag 1), daily average dew point temperature (lag 1), linear, quadratic, and cubic terms for day-of-summer, an indicator variable for 1996 (compared with all other years), and an interaction term between the year indicator and the Olympic period indicator. The exposure period of interest was during the Olympic Games. Therefore we examined the effect of the Olympic Games period compared with its baseline, adjusting for the effect in all other years and allowing for the effect of the Olympic period to vary each year. We then reported the effect of the Olympic Games period compared with its baseline. We ran a similar model including an offset of the log of the daily total noncase (not in the case groups of interest), nonaccidental ED visits and a similar model with indicator variables for each year (with 1995 as the referent year).

Secondary Analyses

For the secondary analyses we replicated the approach of Friedman and colleagues (2001) and performed several alternative analyses to evaluate the sensitivity of those results to modeling choices. This analysis included ED visits to the two pediatric hospitals from residents within the 5-county area during the 73 days of the Olympic Games period and its baseline periods (four weeks before and four weeks after the Olympic Games). Friedman and colleagues (2001) examined the proportion of all ED visits that were due to asthma (asthma ED visits/total ED visits) in relation to the Olympic indicator variable in a Poisson GEE analysis (Zeger and Liang 1986), using an autoregressive correlation structure and controlling for day-of-week (weekday vs. weekend) and minimum temperature lagged one day (i.e., lag 1). We used the same approach for ED visits due to pneumonia, upper respiratory infection, and all respiratory disease groups (the cardiovascular disease groups and COPD were very low in this pediatric population). We also used a Poisson GEE model with the daily number of ED visits as the outcome variable for each case group, and we included an offset of the log of the total nonaccidental and noncase ED visits. To address concerns about the choice of baseline period and the lack of control for time trend, we ran the Poisson GEE models with a shorter baseline period (two weeks before and two weeks after the Olympic Games) as well as Poisson GEE models of the 73-day study period including linear, quadratic, and cubic terms for day-of-summer.

RESULTS

AMBIENT AIR POLLUTION

CO values were missing from site B for 10 of 17 days within the Olympic Games period; therefore, we excluded this site from further analyses. Data from other sites were complete during the Olympic Games period and nearly complete during the Olympic Games baseline periods (the other site for CO, site A, was missing 2 of 73 days; site C

Table 1. Ambient Air Quality Concentrations from Available Monitoring Sites Within the Atlanta 5-County Area for the Period During the Olympic Games, the Baseline Periods Before and After the Olympic Games, and for the 11-Year Combined Olympic Period

Air Quality Metric / Site[a]	Study Periods[b] Baseline Before Mean (SD)	During the Games Mean (SD)	Baseline After Mean (SD)	*P* Values[c] Comparing Before vs. During	*P* Values[c] Comparing After vs. During	11-Year[d] Combined Olympic Period
O_3 (ppb) 8-hr maximum						
Site E	76.3 (20.3)	53.6 (17.0)	68.9 (19.3)	**< 0.001**	**0.031**	65.7 (24.4)
Site C	68.5 (21.4)	45.9 (16.2)	60.6 (17.7)	**< 0.001**	**0.037**	60.9 (22.6)
O_3 (ppb) 1-hr maximum						
Site E	87.7 (22.7)	63.2 (20.6)	83.7 (25.2)	**0.003**	**0.015**	70.7 (36.0)
Site C	81.4 (24.3)	56.4 (19.4)	75.2 (22.5)	**0.002**	**0.022**	67.2 (34.3)
PM_{10} (µg/m^3) 24-hr average						
Site D	37.6 (14.2)	31.2 (10.4)	35.9 (12.1)	0.239	0.454	33.1 (12.5)
NO_2 (ppb) 1-hr maximum						
Site D	49.1 (15.9)	43.7 (8.17)	49.4 (15.6)	0.450	0.404	39.0 (15.6)
Site C	36.2 (13.3)	31.2 (9.89)	32.8 (13.0)	0.397	0.912	28.9 (14.0)
NO_x (ppb) 1-hr maximum						
Site D	18.5 (5.4)	18.2 (3.60)	18.2 (6.4)	0.980	0.990	14.7 (5.7)
CO (ppm) 1-hr maximum						
Site A	2.26 (1.38)	1.55 (0.43)	2.25 (1.40)	0.053	**0.050**	1.48 (0.63)
SO_2 (ppb) 1-hr maximum						
Site E	13.7 (11.0)	14.8 (11.8)	8.32 (9.5)	0.941	0.127	13.6 (16.5)
Site D	13.4 (14.8)	18.3 (13.5)	14.7 (19.9)	0.613	0.766	17.2 (17.6)
Average daily dew point temperature (°F)	66.2 (4.03)	69.2 (1.81)	67.9 (2.46)	**0.005**	0.311	69.1 (3.48)
Average daily temperature (°F)	82.7 (2.62)	80.7 (3.69)	79.2 (2.05)	0.051	0.178	80.5 (3.68)
Total daily precipitation (inches)	0.03 (0.10)	0.14 (0.21)	0.14 (0.32)	0.278	0.999	0.15 (0.39)
Average daily wind speed (mph)	7.40 (2.33)	6.38 (2.04)	5.47 (2.15)	0.295	0.372	7.22 (2.09)
Total daily sunshine (minutes)	723 (67.5)	470 (274)	481 (256)	**< 0.001**	0.984	565 (182)

[a] Sites are shown in Figure 1. Meterologic data were collected at Hartsfield-Atlanta International Airport.

[b] Study Periods include the baseline period before the Olympic Games (June 21–July 18, 1996); the period during the Olympic Games (July 19–August 4, 1996); and the baseline period after the Olympic Games (August 5–September 1, 1996).

[c] Significant *P* values are bolded.

[d] The 11-year combined Olympic period includes July 19–August 4 of years 1993 through 2004, excluding 1996.