RESEARCH REPORT

HEALTH EFFECTS INSTITUTE

Number 148
April 2010

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

Jennifer L. Peel, Mitchell Klein, W. Dana Flanders, James A. Mulholland, and Paige E. Tolbert

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

Jennifer L. Peel, Mitchell Klein, W. Dana Flanders, James A. Mulholland, and Paige E. Tolbert

with a Critique by the HEI Health Review Committee

Research Report 148
Health Effects Institute
Boston, Massachusetts

Trusted Science • Cleaner Air • Better Health

Publishing history: The Web version of this document was posted at *www.healtheffects.org* in April 2010.

Citation for document:

Peel JL, Klein M, Flanders WD, Mulholland JA, Tolbert PE. 2010. Impact of Improved Air Quality During the 1996 Summer Olympic Games in Atlanta on Multiple Cardiovascular and Respiratory Outcomes. HEI Research Report 148. Health Effects Institute, Boston, MA.

Cover paper: made with at least 55% recycled content, of which at least 30% is post-consumer waste; free of acid and elemental chlorine. Text paper: made with 100% post-consumer waste recycled content; acid free; no chlorine used in processing. The book is printed with soy-based inks and is of permanent archival quality.

CONTENTS

Research Report 148

ABOUT HEI

The Health Effects Institute is a nonprofit corporation chartered in 1980 as an independent research organization to provide high-quality, impartial, and relevant science on the effects of air pollution on health. To accomplish its mission, the institute

- Identifies the highest-priority areas for health effects research;
- Competitively funds and oversees research projects;
- Provides intensive independent review of HEI-supported studies and related research;
- Integrates HEI's research results with those of other institutions into broader evaluations; and
- Communicates the results of HEI research and analyses to public and private decision makers.

HEI receives half of its core funds from the U.S. Environmental Protection Agency and half from the worldwide motor vehicle industry. Frequently, other public and private organizations in the United States and around the world also support major projects or certain research programs.

HEI has funded more than 280 research projects in North America, Europe, Asia, and Latin America, the results of which have informed decisions regarding carbon monoxide, air toxics, nitrogen oxides, diesel exhaust, ozone, particulate matter, and other pollutants. These results have appeared in the peer-reviewed literature and in more than 200 comprehensive reports published by HEI.

HEI's independent Board of Directors consists of leaders in science and policy who are committed to fostering the public–private partnership that is central to the organization. The Health Research Committee solicits input from HEI sponsors and other stakeholders and works with scientific staff to develop a Five-Year Strategic Plan, select research projects for funding, and oversee their conduct. The Health Review Committee, which has no role in selecting or overseeing studies, works with staff to evaluate and interpret the results of funded studies and related research.

All project results and accompanying comments by the Health Review Committee are widely disseminated through HEI's Web site (*www.healtheffects.org*), printed reports, newsletters, and other publications, annual conferences, and presentations to legislative bodies and public agencies.

ABOUT THIS REPORT

Research Report 148, *Impact of Improved Air Quality During the 1996 Summer Olympic Games in Atlanta on Multiple Cardiovascular and Respiratory Outcomes,* presents a research project funded by the Health Effects Institute and conducted by Dr. Jennifer L. Peel of the Department of Environmental and Radiological Health Sciences, Colorado State University, Fort Collins, Colorado and her colleagues. This report contains three main sections.

The HEI Statement, prepared by staff at HEI, is a brief, nontechnical summary of the study and its findings; it also briefly describes the Health Review Committee's comments on the study.

The Investigators' Report, prepared by Peel and colleagues, describes the scientific background, aims, methods, results, and conclusions of the study.

The Critique is prepared by members of the Health Review Committee with the assistance of HEI staff; it places the study in a broader scientific context, points out its strengths and limitations, and discusses remaining uncertainties and implications of the study's findings for public health and future research.

This report has gone through HEI's rigorous review process. When an HEI-funded study is completed, the investigators submit a draft final report presenting the background and results of the study. This draft report is first examined by outside technical reviewers and a biostatistician. The report and the reviewers' comments are then evaluated by members of the Health Review Committee, an independent panel of distinguished scientists who have no involvement in selecting or overseeing HEI studies. During the review process, the investigators have an opportunity to exchange comments with the Review Committee and, as necessary, to revise their report. The Critique reflects the information provided in the final version of the report.

PREFACE

HEI's Accountability Research Program

The goal of most air quality regulations is to protect the public's health by implementing regulatory actions or providing economic incentives that help reduce the public's exposure to air pollutants. If this goal is met, air pollution should be reduced, and indicators of public health should improve or at least not deteriorate. Evaluating the extent to which air quality regulations succeed in protecting public health is part of a broader effort — variously termed accountability research, research on regulatory effectiveness, or outcome studies — designed to assess the performance of environmental regulatory policies in general. In recent decades, air quality in the United States and Western Europe has improved substantially, and this improvement is attributable to a number of factors, including increasingly stringent air quality regulations. However, the cost of the pollution-control technologies and mechanisms needed to implement and enforce these regulations is often high. It is therefore prudent to ask whether the regulations have in fact yielded demonstrable improvements in public health and provided information to inform future efforts to do so.

Several U.S. government agencies have concluded that there is a lack of direct evidence about the extent to which air quality regulations have improved health (measured as a decrease in premature mortality and excess morbidity). This finding is well documented by the National Research Council (NRC) in its report *Estimating the Public Health Benefits of Proposed Air Pollution Regulations* (NRC 2002), as well as by the California Air Resources Board, the U.S. Environmental Protection Agency (EPA), the U.S. Centers for Disease Control and Prevention (CDC), and other agencies.

In 2003, the Health Effects Institute (HEI) published a monograph on accountability, Communication 11, *Assessing Health Impact of Air Quality Regulations: Concepts and Methods for Accountability Research* (HEI 2003). This monograph was written by the members of HEI's multidisciplinary Accountability Working Group after a 2001 workshop on the topic. Communication 11 set out a conceptual framework for accountability research and identified the types of evidence required and the methods by which the evidence should be obtained. It has also guided the development of the HEI Accountability Research program, which is discussed below.

Between 2002 and 2004, HEI issued four requests for applications (RFAs) for studies to evaluate the effects of actions taken to improve air quality. Four studies were funded under RFA 04-4, "Measuring the Health Impacts of Actions That Improve Air Quality," one of which was the study by Dr. Jennifer Peel and colleagues described in this Research Report. HEI also funded five additional accountability studies resulting from other RFAs (see table).

This preface describes both the framework of accountability research as it relates to air quality regulations and HEI's Accountability Research program.

BACKGROUND

The first step in assessing the effectiveness of air quality regulations is to measure emissions of the targeted pollutants to see whether they have in fact decreased as intended. A series of intermediate assessments, described in detail below, are needed in order to accurately measure the adverse health effects associated with air pollution to see whether they, too, decreased in incidence or severity relative to emissions. Some accountability studies to date have used hypothetical scenarios (comparing estimated outcomes under existing and more stringent regulations) and risk estimates obtained from epidemiologic studies in an attempt to quantify past effects on health and to predict future effects (U.S. EPA 1999). However, more extensive validation of these estimates with data on actual outcomes would be helpful.

HEI's Accountability Research Program[a]			
RFA	Investigator (Institution)	Study Title	Intervention
RFA 02-1			
	Douglas Dockery (Harvard School of Public Health, Boston, Mass.)	"Effects of Air Pollution Control on Mortality and Hospital Admissions in Ireland" (in review)	Coal ban in Irish cities
	Annette Peters (GSF–National Research Center for Environment and Health, Neuherberg, Germany)	"Improved Air Quality and Its Influences on Short-Term Health Effects in Erfurt, Eastern Germany" (published as HEI Research Report 137, 2009)	Switch from brown coal to natural gas for home heating and power plants, changes in motor vehicle fleet after reunification of Germany
RFA 04-1			
	Frank Kelly (King's College London, London, U.K.)	"Congestion Charging Scheme in London: Assessing Its Impact on Air Quality and Health" (in press)	Measures to reduce traffic congestion in the inner city of London
RFA 04-4			
	Frank Kelly (King's College London, London, U.K.)	"The London Low Emission Zone Baseline Study" (in press)	Measures to exclude most-polluting vehicles from entering greater London
	Richard Morgenstern (Resources for the Future, Washington, D.C.)	"Accountability Assessment of Title IV of the Clean Air Act Amendments of 1990" (underway)	Measures to reduce sulfur emissions from power plants east of the Mississippi River
	Curtis Noonan (University of Montana, Missoula, Mont.)	"Assessing the Impact on Air Quality and Children's Health of Actions Taken to Reduce $PM_{2.5}$ Levels from Woodstoves" (underway)	Woodstove change-out program
	Jennifer Peel (Colorado State University, Fort Collins, Colo.)	"Impact of Improved Air Quality During 1996 Atlanta Olympic Games on Multiple Cardiorespiratory Outcomes" (published as HEI Research Report 148, 2010)	Measures to reduce traffic congestion during the Atlanta Olympics
	Chit-Ming Wong (University of Hong Kong, Hong Kong)	"Impact of the 1990 Hong Kong Legislation for Restriction on Sulfur Content in Fuel" (in review)	Measures to reduce sulfur content in fuel for motor vehicles and power plants
RFPA 05-3			
	Junfeng (Jim) Zhang (University of Medicine and Dentistry of New Jersey, Piscataway, N.J.)	"Molecular and Physiological Responses to Drastic Changes in PM Concentration and Composition" (underway)	Measures to improve air quality during the Beijing Olympics

[a] Abbreviations: RFA, Request for Application; RFPA, Request for Preliminary Application. As of 2008, GSF–National Research Center for Environment and Health is now the Helmholtz Zentrum München–German Research Center for Environmental Health.

The long-term improvements in U.S. air quality have been associated with improved health in retrospective epidemiologic studies (Chay and Greenstone 2003; Laden et al. 2006; Pope et al. 2009). Considerable challenges, however, are inherent in the assessment of the health effects of air quality regulations. Different regulations go into effect at different times, for example, and may be implemented at different levels of government (e.g., national, regional, or local). Their effectiveness therefore needs to be assessed in ways that take into account the varying times of implementation and levels of regulation. In addition, other changes at the same time and place might have confounded an apparent association between pollution reduction and improved health, such as economic trends (e.g., in changes in employment), improvements in health care, and behavioral changes (e.g., staying indoors when government warnings indicate pollution concentrations are high). Moreover, adverse health effects that might have been caused by exposure to air pollution can also be caused by other environmental risk factors (some of which changed over the same time periods as the air pollution concentrations). These challenges become more pronounced when regulations are implemented over long periods and when changes in air quality and health outcomes are not seen immediately, thus increasing the chance for confounding by other factors. For these reasons, scenarios in which regulations are expected to have resulted in rapid changes in air quality tend to be among the first, and most likely, targets for investigation, rather than evaluations of complex regulatory programs implemented over the long term. Studies in Ireland by Clancy and colleagues (2002) and in Hong Kong by Hedley and colleagues (2002) are examples of such scenarios.

These inherent challenges are well documented in Communication 11 (HEI 2003), which was intended to advance the concept of accountability research and to foster the development of accountability methods and studies throughout the relevant scientific and policy communities. In addition, recent advances in data collection and analytic techniques provide an unprecedented opportunity to improve our assessments of the effects of air quality interventions.

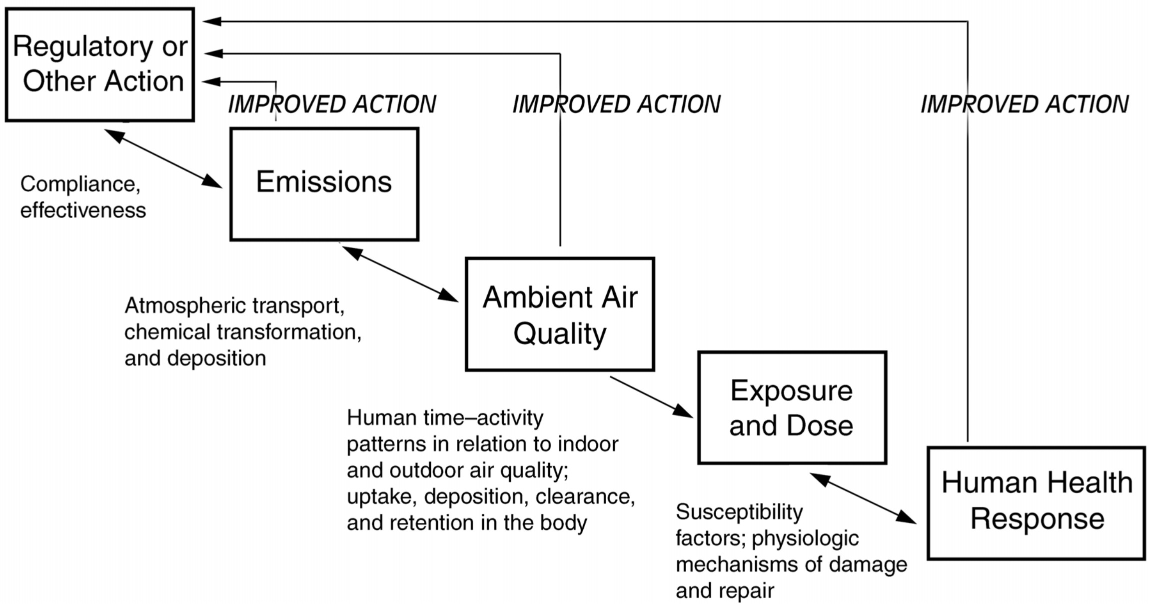
THE CHAIN OF ACCOUNTABILITY

The NRC's Committee on Research Priorities for Airborne Particulate Matter set out a conceptual framework for linking air pollution sources to adverse health effects (NRC 1998). This framework can be used to identify factors along a "chain of accountability" (see figure), each stage of which affords its own opportunities for making quantitative measurements of the intended improvements.

At the first stage (regulatory action), one can assess whether controls on source emissions have in fact been put into place. At the second stage (emissions), one can determine whether controls on sources have indeed reduced emissions, whether emitters have changed their practices, and whether there have been unintended consequences. At the third stage (ambient air quality), one can assess whether controls on sources and reductions in emissions have resulted in improved air quality. At the fourth stage (personal or population exposure), one can assess whether the improvement in air quality has reduced people's actual exposure and whether susceptible subpopulations (those most likely to experience adverse health effects) have benefited. At this stage, it is important to take into account changes in time–activity patterns that could either increase or reduce exposure. The actual dose that an individual's organs may be exposed to should also be considered (i.e., whether reductions in exposure have led to reductions in concentrations in body tissues such as the lung). Finally, at the fifth stage (human health response), one can assess whether risks to health have declined, given the evidence about changes in health outcomes such as morbidity and mortality that have resulted from changes in exposure. The challenge at this stage is to investigate the health outcomes that are most directly related to exposure to air pollution.

At each stage in the chain of events, the opportunity exists to collect evidence that either validates the assumptions that motivated the intervention or points to ways in which the assumptions were incorrect. The collection of such evidence can thus ensure that future interventions are maximally effective.

Ultimately, the framework for accountability research will need to encompass investigations of the broader consequences of regulations, not just the



The Chain of Accountability. Each box represents a stage in the process between regulatory action and human health responses to air pollution. Arrows connecting the stages indicate possible directions of influence. The text below the arrows identifies factors affecting the effectiveness of regulatory actions (referred to as "accountability") at each stage. At several of the stages, knowledge gained from accountability studies can provide valuable feedback for improving regulatory or other actions (from Health Effects Institute 2003, Figure 1.2).

intended consequences. Unintended consequences should also be investigated, along with the possibility that risks to public health in fact increased, as discussed by Wiener (1998) and others who have advanced the concept of a so-called portfolio of effects of a regulation.

HEI'S ACCOUNTABILITY RESEARCH PROGRAM

HEI's Accountability Research program currently includes nine studies. The study by Dr. Jennifer Peel and colleagues that is presented in this report is the second of the nine to be published; four additional studies are in review and are expected to be published in 2010. The remaining three studies are still underway and are expected to be completed during 2010.

These studies involve the measurement of indicators along the entire chain of events, from regulatory or other interventions to human health outcomes. Some of the studies focused on interventions that are implemented over relatively short periods of time, such as a ban on the sale of coal, the replacement of old wood stoves with more efficient, cleaner ones, reductions in the sulfur content of fuels, and measures to reduce traffic. Other groups focused on longer-term, wider-ranging interventions or events; for instance, one study assessed complex changes associated with the reunification of the former East and West Germany, including a switch from brown coal to natural gas for fueling power plants and home-heating systems and an increase in the numbers of modern diesel-powered vehicles in eastern Germany. HEI is also supporting research, including the development of methods, in an especially challenging area — namely, the effects of regulations that are implemented incrementally over extended periods of time, such as those resulting from Title IV of the 1990 Clean Air Act Amendments (U.S. EPA 1990), which aimed at reducing sulfur dioxide emissions from power plants by requiring compliance with prescribed emission limitations. Studies on accountability funded by HEI to date are summarized in the table and described in more detail in an interim evaluation of the HEI Accountability Research program (van Erp and Cohen 2009).

FUTURE DIRECTIONS

In addition to the completion, review, and publication of these nine accountability studies, HEI has also funded the development of two Web sites intended to enhance transparency and provide other researchers with access to extensive data and software from HEI-funded studies:

1. Data and software from the National Morbidity, Mortality, and Air Pollution Study (NMMAPS), as described by Zeger and colleagues (2006) (data available at the Johns Hopkins Bloomberg School of Public Health Web site *www.ihapss.jhsph.edu*) and
2. Data from the National Particle Components Toxicity Initiative (NPACT) on concentrations of components of particulate matter with an aerodynamic diameter less than or equal to 2.5 µm ($PM_{2.5}$) collected at or near the 54 sites in the EPA's $PM_{2.5}$ Chemical Speciation Trends Network (STN) (data available at the Atmospheric and Environment Research, Inc., Web site *http://hei.aer.com*).

The data on pollution and health from a large number of U.S. cities, as documented and regularly updated by the NMMAPS team and made available on the Internet-Based Health and Air Pollution Surveillance System (iHAPSS) Web site, constitute a valuable resource that allows other researchers to undertake additional analyses, possibly including further accountability studies. The STN Web site provides scientists an opportunity to investigate specific questions about concentrations of $PM_{2.5}$ components and their association with adverse health effects in regions covered by the STN network and to address questions related to accountability when interventions in these regions are being planned.

In January 2008, HEI co-organized and cosponsored, with the CDC's Environmental Public Health Tracking Program and the EPA, a workshop entitled "Methodologic Issues in Environmental Public Health Tracking of Air Pollution Effects." The workshop was part of an effort to implement the initiative outlined in HEI's Strategic Plan for 2005 through 2010 (HEI 2005) to "build networks with the U.S. Centers for Disease Control and Prevention and state public health tracking programs to facilitate accountability research." Building on the work of the CDC's Environmental Public Health Tracking Program (see the CDC Web site *www.cdc.gov/nceh/tracking/*) in the development of standardized measures of air pollution–related effects on health at the state and local levels in the United States, the workshop brought together representatives of state and federal agencies and academic researchers to discuss methodologic issues in the development of such measures and made recommendations for their further development and application. The recommendations were provided in a September 2008 report to the CDC, and the proceedings were published in the journal *Air Quality, Atmosphere & Health* in December 2009 (e.g., Matte et al. 2009). HEI will continue to seek opportunities to work with the CDC and the EPA to apply methods newly developed for tracking public health to the assessment of the effectiveness of environmental regulations.

As a part of its new Strategic Plan for 2010 through 2015 (HEI 2010a), HEI will look closely at opportunities for unique new contributions to accountability research. Proceedings from an accountability research planning workshop held in December 2009 are expected to be published in the Spring of 2010 and will include key recommendations for future research (HEI 2010b). Investigators who have identified a distinctive opportunity to evaluate the effects of environmental regulations on air pollution and human health are encouraged to contact HEI.

REFERENCES

Atmospheric and Environmental Research, Inc. (San Ramon, CA). HEI Air Quality Database. *http://hei.aer.com.* Accessed 3/26/10.

Chay KY, Greenstone M. 2003. The impact of air pollution on infant mortality: Evidence from geographic variation in pollution shocks induced by a recession. Q J Economics 118:1121–1167.

Clancy L, Goodman P, Sinclair H, Dockery DW. 2002. Effect of air-pollution control on death rates in Dublin, Ireland: An intervention study. Lancet 360:1210–1214.

Health Effects Institute. 2003. Assessing Health Impact of Air Quality Regulations: Concepts and Methods for

Accountability Research. HEI Communication 11. Health Effects Institute, Boston, MA.

Health Effects Institute. 2005. HEI Strategic Plan for Understanding Health Effects of Air Pollution. Health Effects Institute, Boston, MA.

Health Effects Institute. 2010a. HEI Strategic Plan for Understanding the Health Effects of Air Pollution 2010–2015. Health Effects Institute, Boston, MA.

Health Effects Institute. 2010b. Proceedings of an HEI Workshop on Further Research to Assess the Health Impacts of Actions Taken to Improve Air Quality. Communication 15. Health Effects Institute, Boston, MA. In press.

Hedley AJ, Wong CM, Thach TQ, Ma S, Lam TH, Anderson HR. 2002. Cardiorespiratory and all-cause mortality after restrictions on sulphur content of fuel in Hong Kong: An intervention study. Lancet 360:1646–1652.

Johns Hopkins Bloomberg School of Public Health (Baltimore, MD). Internet-Based Health and Air Pollution Surveillance System (last updated 3/19/05). *www.ihapss.jhsph.edu.* Accessed 3/26/10.

Laden F, Schwartz J, Speizer FE, Dockery DW. 2006. Reduction in the particulate air pollution and mortality: Extended follow-up of the Harvard Six Cities study. Am J Respir Crit Care Med 173:667–672.

Matte TD, Cohen A, Dimmick F, Samet J, Sarnat J, Yip F, Jones N. 2009. Summary of the workshop on methodologies for environmental public health tracking of air pollution effects. Air Qual Atmos Health 2:177–184.

National Research Council (U.S.). 1998. Research Priorities for Airborne Particulate Matter: I. Immediate Priorities and a Long-Range Research Portfolio. National Academy Press, Washington, D.C.

National Research Council (U.S.). 2002. Estimating the Public Health Benefits of Proposed Air Pollution Regulations. National Academy Press, Washington, D.C.

Pope CA III, Ezzati M, Dockery DW. 2009. Fine-particulate air pollution and life expectancy in the United States. N Engl J Med 360:376–386.

U.S. Centers for Disease Control and Prevention. Environmental Public Health Tracking Program. *www.cdc.gov/nceh/tracking/*. Accessed 3/26/10.

U.S. Environmental Protection Agency. 1990. A Bill to Amend the Clean Air Act to Provide for Attainment and Maintenance of Health Protective National Ambient Air Quality Standards, and for Other Purposes. S 1630, 101st Cong, 2nd Sess.

U.S. Environmental Protection Agency. 1999. Benefits and Costs of the Clean Air Act 1990 to 2010: Report to Congress. EPA/410/R-99-001. Office of Air and Radiation, Washington, D.C.

van Erp AM, Cohen AJ. 2009. HEI's Research Program on the Impact of Actions to Improve Air Quality: Interim Evaluation and Future Directions. Communication 14. Health Effects Institute, Boston, MA.

Wiener J. 1998. Managing the iatrogenic risks of risk management. Risk Health Safety Environ 9:39–82.

Zeger, SL, McDermott A, Dominici F, Peng R, and Samet J. 2006. Internet-Based Health and Air Pollution Surveillance System. Communication 12, Health Effects Institute, Boston, MA.

HEI STATEMENT

Synopsis of Research Report 148

Impact of Regional Air Quality Improvements During the Atlanta Olympic Games

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 achieving the intended improvements in public health. 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.

Dr. Jennifer Peel of Colorado State University proposed to evaluate the effect of a short-term, temporary intervention to reduce traffic congestion during the 1996 Summer Olympic Games in Atlanta, Georgia. A previous study of the Atlanta traffic intervention by Friedman and colleagues had shown a decrease in acute care visits for pediatric asthma and a concomitant decrease in concentrations of ozone, PM_{10} (particulate matter with an aerodynamic diameter $\leq$ 10 µm), and carbon monoxide during the Olympic Games compared with the weeks before and after the games. However, important questions remained unanswered. It was not clear to what extent normal seasonal patterns in pollutant concentrations or health outcomes may have influenced the results. It is also possible that health care usage during the Olympic Games changed because residents may have changed their behavior because of the games.

Peel and colleagues proposed to address these questions by evaluating wider time windows surrounding the Olympic Games period and extending the analyses to earlier and later years and to broader geographic areas. They also proposed to evaluate additional respiratory and cardiovascular disease outcomes in different age groups. The HEI Research Committee thought that the additional analyses would enhance our understanding of the possible effects of this temporary traffic intervention on health outcomes and recommended the study for funding.

APPROACH

Peel and colleagues used emergency department data for 1995 though 2004, which had been collected as part of the Study of Particles and Health in Atlanta, to examine the associations between daily air quality and daily emergency department visits for cardiovascular and respiratory outcomes. The database had data for more than 25,000 emergency department visits, for all causes, made by Atlanta residents to 12 hospitals (including 2 pediatric hospitals) during the Olympic Games. The investigators also obtained daily ambient air quality and meteorologic data for five central counties within the Atlanta area as well as for more rural sites in Georgia and for six other urban areas in the Southeastern United States. In addition, they obtained traffic data from the Georgia Department of Transportation, which in 1996 conducted traffic counts at 18 sites within the five counties studied.

The investigators compared mean pollutant concentrations and traffic counts between the Olympic and baseline periods using a time-series approach. Numbers of daily emergency department visits were analyzed using Poisson generalized linear models. The 73-day period of interest included the 17 days of

This Statement, prepared by the Health Effects Institute, summarizes a research project funded by HEI and conducted by Dr. Jennifer L. Peel at Colorado State University, Fort Collins, CO, and colleagues. Research Report 148 contains both the detailed Investigators' Report and a Critique of the study prepared by the Institute's Health Review Committee.

the Olympic Games and 28 days immediately before and after the games (baseline periods). Primary analyses were performed of emergency department visits for the 73-day period in 1996 as well as for the surrounding years (1995 and 1997–2004). Secondary analyses were conducted on the short 73-day time series (1996 Olympic and baseline periods only), similar to the analyses by Friedman and colleagues. The investigators conducted a number of sensitivity analyses using generalized estimating equations to evaluate the effects of model choices and choices of baseline periods on the estimates.

RESULTS AND INTERPRETATION

Peel and colleagues successfully conducted an extensive evaluation of health outcomes associated with air quality changes during the Olympic Games in Atlanta that critically expanded the initial evaluation by Friedman and colleagues. They confirmed that Atlanta experienced a significant decline in ozone concentrations of 20% to 30% during the Olympic Games, with less pronounced decreases in concentrations of carbon monoxide, PM_{10}, and nitrogen dioxide. Importantly, Peel and colleagues found that similar declines in ozone concentrations were observed throughout Georgia and the Southeastern United States. In its independent review of the study, the HEI Health Review Committee agreed with the investigators that the regional nature of the reduction in ozone concentrations was due to meteorologic conditions; this has made it difficult to assess whether and to what extent the measures to reduce traffic during the Olympic Games contributed to air quality improvements in downtown Atlanta.

The investigators reported up to a 20% decline in weekday peak morning traffic counts at four sites in Atlanta and declines of 2% to 15% at the remaining sites; the observed declines were somewhat smaller than that reported by Friedman and colleagues (i.e., 22.5%). In addition, the daily total number of cars commuting into Atlanta was not changed. Thus, it remains unclear whether the measures to improve traffic flow during the Olympic Games had significantly reduced traffic or improved air quality.

In their primary analyses, which were adjusted for seasonal trends in air pollutant concentrations and health outcomes during the years before and after the Olympic Games, the investigators did not find significant reductions in the number of emergency department visits for respiratory or cardiovascular health outcomes in adults or children. They reported that the risk estimates often had large confidence intervals, indicating uncertainty in the results, and that they were sensitive to the choice of analytic model. Because the 17-day period of the Olympic Games was short, it is possible that the daily number of emergency department visits was too low to adequately test the hypothesis that health outcomes would be affected. When they analyzed the 73-day period comprising the Olympic and adjacent baseline periods without adjusting for similar trends in surrounding years (secondary analyses), Peel and colleagues observed reductions in emergency department visits for upper respiratory infections for all age groups and for pediatric ages during the Olympic Games, but they could not confirm the observation by Friedman and colleagues that the number of pediatric emergency care visits for asthma was substantially reduced during the Olympic Games. (It should be noted that Peel and colleagues used a different database.)

The Committee thought that the study by Peel and colleagues was designed carefully, but noted that it was constrained by the short duration of the intervention, the small reductions in air pollution concentrations, the low daily numbers of emergency department visits, difficulty of isolating the effects of an intervention from usual temporal patterns in health care usage, and a lack of control areas. Although the investigators examined important potential confounders that were not addressed in the study by Friedman and colleagues, the retrospective nature of the study limited their ability to evaluate behavioral changes — such as Atlanta residents potentially leaving the city during the Olympic period — that may have influenced the results.

This study illustrates the importance of evaluating appropriate time windows surrounding interventions, properly adjusting for seasonal and other trends that may influence the results, and using control areas. Evaluation of short-term air quality interventions remains challenging, especially one as short as 17 days, because changes in meteorologic conditions could easily overwhelm any changes that might be due to the intervention. More broadly, this study emphasizes the importance of examining the full chain of events that might result from any such intervention — for example, asking first whether the intervention actually reduced traffic, then asking whether that reduction in traffic resulted in improved air quality, and then finally examining whether any observed improvements in air quality actually resulted in health improvements.

INVESTIGATORS' REPORT

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

Jennifer L. Peel, Mitchell Klein, W. Dana Flanders, James A. Mulholland, and Paige E. Tolbert

Department of Environmental and Radiological Health Sciences, Colorado State University, Fort Collins, CO (J.L.P.); Department of Environmental and Occupational Health, (M.K., P.E.T.); and Department of Epidemiology (M.K., W.D.F., P.E.T.), Rollins School of Public Health, Emory University, Atlanta, GA; and Department of Civil and Environmental Engineering, Georgia Institute of Technology, Atlanta, GA (J.A.M.)

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.

Although this document was produced with partial funding by the United States Environmental Protection Agency under Assistance Award CR–83234701 to the Health Effects Institute, it has not been subjected to the Agency's peer and administrative review and therefore may not necessarily reflect the views of the Agency, and no official endorsement by it should be inferred. The contents of this document also have not been reviewed by private party institutions, including those that support the Health Effects Institute; therefore, it may not reflect the views or policies of these parties, and no endorsement by them should be inferred.

* 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

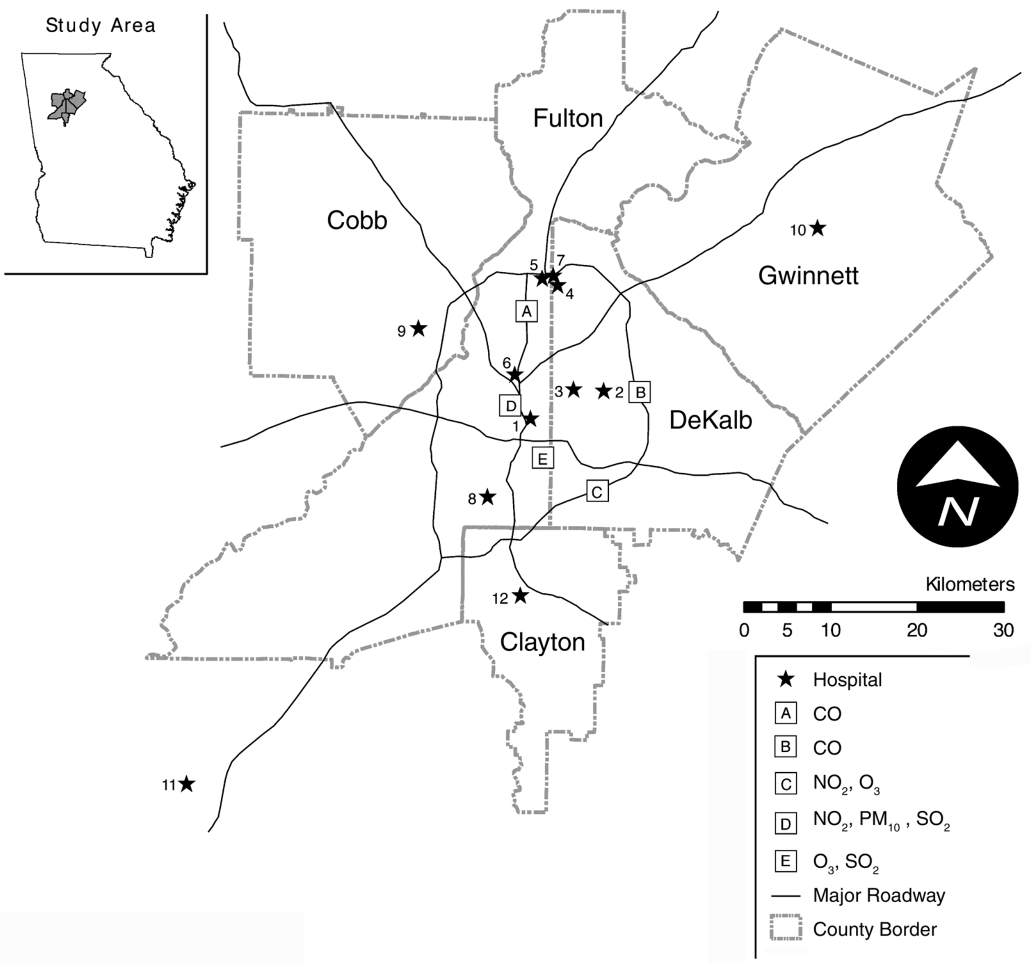


Figure 1. Map showing the five counties of the Atlanta area, the study hospitals at locations 1–12, and locations of the air quality monitor sites (A: Roswell Road, B: DeKalb Tech, C: South DeKalb, D: Georgia Institute of Technology, E: Confederate Avenue). The pediatric hospitals are at locations 3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

Olympic Games included promoting the use of public transportation, increased availability of public transportation, and promoting alternative work hours and telecommuting to local businesses (GA EPD 1996). These efforts were considered to be largely successful (GA EPD 1996; Friedman et al. 2001; NCHRP 2001); mass transit ridership doubled (including visitors to the Olympic Games) and morning rush hour traffic counts decreased (GA EPD 1996). The GA EPD concluded that O_3 concentrations measured during the Olympic Games were lower than meteorologically based predicted concentrations (GA EPD 1996).

AMBIENT AIR QUALITY MEASUREMENTS

We obtained daily ambient air quality data from the EPA Air Quality System (*www.epa.gov/ttn/airs/airsaqs/*) and the Georgia Department of Natural Resources for available sites within the 5-county area for the summers of 1993 through 2004 (Figure 1). Data included 24-hour average PM_{10} mass, 8-hour maximum O_3, and 1-hour maximums for O_3, nitrogen dioxide (NO_2), total oxides of nitrogen (NO_x), sulfur dioxide (SO_2), and CO. O_3 was measured at two sites, PM_{10} at one site, NO_2 at two sites, CO at two sites, and SO_2 at two sites. PM_{10} concentrations were measured using the Federal Reference Method; gaseous pollutants were measured using standard U.S. EPA methods. O_3 concentrations in Atlanta are low during the winter months and typically are measured only from March through October; the remaining pollutants are measured year-round. A previous analysis of the Atlanta area showed that sites for secondary pollutants (O_3 and $PM_{2.5}$ [PM $\leq$ 2.5 µm in aerodynamic diameter]) were more spatially representative than sites for primary pollutants (CO, SO_2, NO_x, elemental carbon content of $PM_{2.5}$) (Wade et al. 2006). Although primary pollutants from traffic have substantial spatial variation, the concentrations tend to have moderate temporal correlation across space (Wade et al. 2006). Meteorologic conditions for the 5-county Atlanta area (including temperature, dew point temperature, amount of sunshine, and precipitation) were obtained from the National Climatic Data Center network from measurements taken at Hartsfield-Atlanta International Airport.

We also obtained available air quality data for sites outside the 5-county Atlanta area from the EPA Air Quality System and meteorologic data for these sites from the National Climatic Data Center. This included sites within the 20-county Atlanta MSA but outside of the 5-county area, sites in other parts of Georgia, and other metropolitan sites within the Southeastern United States.

TRAFFIC COUNTS

We obtained hourly traffic counts from the Georgia Department of Transportation for 18 sites within the 5-county area for 1996, including 4 sites located near the downtown area. For each site, we calculated a daily 1-hour maximum for weekday mornings (4 AM–10 AM), and total daily counts for weekdays.

ED DATA

We collected electronic billing records with information on over 10 million ED visits to 40 hospitals in the 20-county Atlanta MSA for the summers of 1993 through 2004. The information included primary *International Classification of Diseases*, 9th Revision (ICD-9) diagnostic codes, secondary ICD-9 diagnostic codes, age, date of birth, sex, race, payment information, and residential ZIP code. Repeat ED visits within a single day were counted as a single visit. Twelve hospitals provided data during the Olympic Games; therefore, our primary analyses included ED visits to those 12 hospitals (identified by numbers 1–12 in Figure 1), including the pediatric emergency departments of the hospitals studied by Friedman and colleagues (2001) (hospitals 3 and 4). We excluded the data from 1993 and 1994 because several of the 12 hospitals did not provide data during this time (our primary analyses included data for 1995–2004). The ED database has been previously described (Metzger et al. 2004; Peel et al. 2005).

Respiratory case groups of interest were defined using the primary ICD-9 diagnostic codes (all 2-digit extensions were used unless otherwise specified): asthma (493, 786.09), chronic obstructive pulmonary disease (COPD; 491, 492, 496), upper respiratory infection (460–466, 477), pneumonia (480–486), and a combined respiratory disease group comprising all four case groups. Cardiovascular disease groups of interest were similarly defined as the following: ischemic heart disease (410–414), acute myocardial infarction (410), cardiac dysrhythmias (427), congestive heart failure (428), peripheral and cerebrovascular disease (433–437, 440, 443, 444, 451–453), and a combined cardiovascular disease group comprising all five case groups. We assessed the adequacy of the modeling approach using ED visits for finger wounds (883.0), an outcome group that has comparable temporal variations to the outcomes of interest, but is expected to be unrelated to air pollution. We separately assessed ED visits identified as Medicaid visits in the billing records, and we examined age-specific case groups (pediatric, 2–18 years; adult, 19–64 years; older adult, $\geq$ 65 years).

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 non-case (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]			*P* Values[c] Comparing Before vs. During	*P* Values[c] Comparing After vs. During	11-Year[d] Combined Olympic Period
	Baseline Before Mean (SD)	During the Games Mean (SD)	Baseline After Mean (SD)			
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.

Table 2. Ambient Air Quality Concentrations from Available Monitoring Sites in Rural Areas Outside the Atlanta 5-County Area for the Period During the Olympic Games and for the Baseline Periods Before and After the Olympic Games

Air Quality Metric / Location	Study Periods[a]			*P* Values[b]	*P* Values[b]
	Baseline Before Mean (SD)	During the Games Mean (SD)	Baseline After Mean (SD)	Comparing Before vs. During	Comparing After vs. During
Monitoring Sites Within the 20-County Atlanta MSA but Outside of the 5-County Area					
O_3 (ppb) 8-hr maximum					
Yorkville	71.8 (16.4)	52.4 (12.7)	67.3 (12.9)	**< 0.001**	**0.003**
NO_2 (ppb) 1-hr maximum					
Yorkville	5.23 (2.54)	5.18 (4.43)	10.9 (6.99)	1.000	**0.002**
CO (ppm) 1-hr maximum					
Yorkville	0.28 (0.10)	0.22 (0.09)	0.36 (0.16)	0.355	**0.002**
SO_2 (ppb) 1-hr maximum					
Stilesboro	16.9 (27.3)	7.12 (7.25)	6.64 (7.28)	0.185	0.996
Georgia Monitoring Sites Outside of the 20-County Atlanta MSA					
O_3 (ppb) 8-hr maximum					
Chatham County, Savannah	50.3 (19.7)	35.5 (7.28)	44.7 (11.5)	**0.004**	0.105
Dawson County	59.5 (9.97)	49.4 (6.97)	55.8 (8.59)	**0.001**	0.062
Fannin County	60.5 (12.1)	45.4 (8.17)	45.0 (7.33)	**< 0.001**	0.993
Muscogee County, Columbus	59.3 (18.3)	43.5 (10.8)	56.6 (10.5)	**0.002**	**0.009**
Richmond County, Augusta	63.1 (19.6)	51.0 (13.4)	53.2 (12.2)	**0.038**	0.889
SO_2 (ppb) 1-hr maximum					
Chatham County, Savannah	11.0 (14.1)	8.18 (9.02)	7.33 (4.24)	0.662	0.961
Fannin County	20.8 (20.4)	24.9 (36.8)	22.8 (19.4)	0.855	0.961
Floyd County, Rome	4.11 (9.57)	9.65 (18.83)	9.00 (11.66)	0.353	0.986
Muscogee County, Columbus	8.33 (10.5)	5.24 (5.78)	5.39 (5.78)	0.431	0.998

[a] 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).

[b] Significant *P* values are bolded.

was missing 1 day for NO_2; site D was missing 2 days for NO_2; site C was missing 1 day for O_3; all other sites had data for all 73 days).

At the two O_3 monitoring sites within the 5-county Atlanta area, mean concentrations of 8-hour maximum O_3 were an average of 23 ppb lower (30%) during the Olympic Games period compared with the baseline period before the Olympic Games, and an average of 15 ppb lower (22%) during the Olympic Games period compared with the baseline period after the Olympic Games (Table 1). Mean concentrations of 24-hour PM_{10}, 1-hour maximum CO (at one CO site), and 1-hour maximum NO_2 were also reduced during the Olympic Games period compared with its baseline periods, although to a lesser extent than was O_3, while mean concentrations of SO_2 were unchanged or slightly higher (Table 1). Similar patterns for pollutant concentrations, particularly for O_3 and PM_{10}, were observed in several years (1995, 1998, and 2001), but not in all years examined (1993–2004) (results not presented). Mean concentrations of 8-hour maximum O_3 during the Olympic Games period were 20% lower than the mean concentrations for the 11-year combined Olympic period, while the mean concentrations of other pollutants were comparable during these periods (Table 1). Mean daily minutes of sunshine were substantially lower during the Olympic Games period and the baseline period after the Olympic Games compared with the baseline period before the Olympic Games (Table 1).

Similar patterns for 1-hour maximum and 8-hour maximum O_3 concentrations were observed for monitoring sites in rural areas outside of the Atlanta area (Table 2) and for 1-hour maximum O_3 in urban areas of the Southeastern United States (Table 3). In both cases, concentrations were reduced during the Olympic Games period compared with

Table 3. Ambient Air Quality Concentrations from Selected Monitoring Sites in Urban Areas of the Southeastern United States for the Period During the Olympic Games and for the Baseline Periods Before and After the Olympic Games

	Study Periods[a]				
Air Quality Metric / Location	Baseline Before Mean (SD)	During the Games Mean (SD)	Baseline After Mean (SD)	*P* Values[b] Comparing Before vs. During	*P* Values[b] Comparing After vs. During
O_3 (ppb) 1-hr maximum					
Birmingham, AL, Site 1	70.0 (26.0)	44.0 (21.0)	63.0 (17.0)	**< 0.001**	**0.018**
Birmingham, AL, Site 2	78.0 (29.0)	49.0 (20.0)	64.0 (17.0)	**< 0.001**	0.113
Birmingham, AL, Site 3	68.0 (15.0)	45.0 (16.0)	60.0 (13.0)	**< 0.001**	**0.002**
Birmingham, AL, Site 4	72.0 (21.0)	48.0 (20.0)	64.0 (14.0)	**< 0.001**	**0.015**
Tallahassee, FL	49.0 (20.0)	40.0 (8.0)	50.0 (10.0)	0.114	0.093
Charlotte, NC, Site 1	84.0 (22.0)	70.0 (14.0)	72.0 (16.0)	**0.034**	0.922
Charlotte, NC, Site 2	80.0 (22.0)	66.0 (17.0)	72.0 (16.0)	**0.048**	0.457
Chattanooga, TN, Site 1	77.1 (13.9)	62.9 (15.7)	74.2 (19.3)	**0.035**	0.117
Chattanooga, TN, Site 2	72.0 (15.0)	55.6 (15.5)	70.6 (14.3)	**0.002**	**0.005**
Knoxville, TN	83.0 (16.0)	66.0 (21.0)	81.0 (15.0)	**0.007**	**0.015**
Nashville, TN, Site 1	66.0 (17.0)	51.0 (16.0)	71.0 (14.0)	**0.008**	**< 0.001**
Nashville, TN, Site 2	78.0 (21.0)	64.0 (12.0)	75.0 (13.0)	**0.012**	0.072
NO_2 (ppb) 1-hr maximum					
Charlotte, NC, Site 1	35.0 (15.0)	30.0 (9.0)	29.0 (9.0)	0.367	0.993
Nashville, TN, Site 1	39.0 (12.0)	36.0 (8.0)	40.0 (10.0)	0.523	0.366
CO (ppm) 1-hr maximum					
Birmingham, AL, Site 1	2.03 (1.33)	1.57 (1.26)	2.20 (1.18)	0.466	0.244
Charlotte, NC, Site 1	1.07 (0.52)	1.06 (0.53)	1.17 (0.39)	0.999	0.762
Knoxville, TN	1.70 (0.74)	1.81 (0.71)	1.88 (0.59)	0.867	0.941
PM_{10} (µg/m^3) 24-hr average					
Birmingham, AL, Site 5	42.2 (19.2)	35.3 (12.9)	52.0 (19.5)	0.432	**0.010**
Birmingham, AL, Site 6	37.6 (14.9)	32.6 (13.4)	41.1 (12.9)	0.479	0.118

[a] 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).

[b] Significant *P* values are bolded.

its baseline periods. The urban areas experiencing reduced O_3 concentrations were cities in Alabama (Birmingham, 147 miles from Atlanta), Tennessee (Chattanooga, 118 miles from Atlanta; Knoxville, 202 miles from Atlanta; Nashville, 250 miles from Atlanta), and North Carolina (Charlotte, 244 miles from Atlanta) (Table 3).

Plots of air pollutant concentrations from sites within the 5-county area are shown in Figures 2–10; pollutant concentrations for year 1996 and for the mean of years 1995 and 1997–2004 are plotted for June 21 through September 1. Although these plots are confounded by secular trends occurring over years 1995 through 2004 (largely decreasing air pollutant concentrations over the years), the patterns during the Olympic period are similar in 1996 compared with the other years.

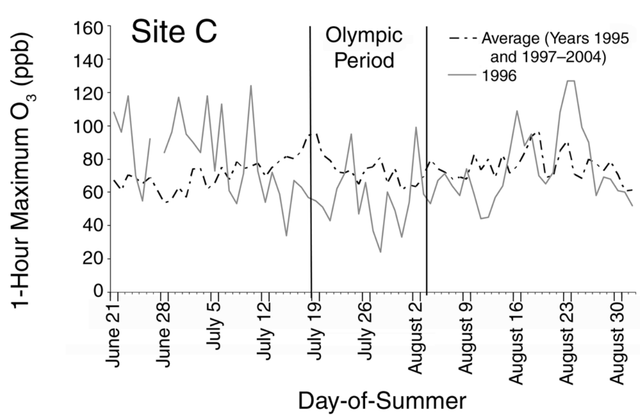


Figure 2. Time-series plots of daily 1-hour maximum O_3 concentration for 1996 and for the average of years 1995 and 1997–2004 (site C).

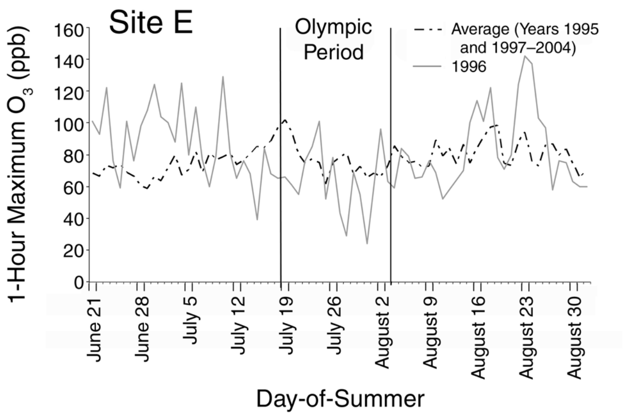


Figure 3. Time-series plots of daily 1-hour maximum O_3 concentration for 1996 and for the average of years 1995 and 1997–2004 (site E).

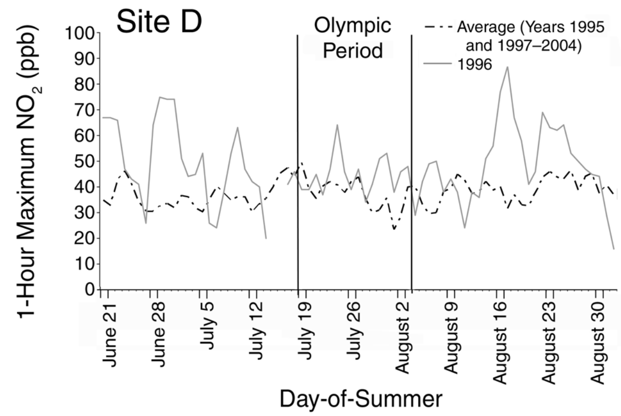


Figure 6. Time-series plots of daily 1-hour maximum NO_2 concentration for 1996 and for the average of years 1995 and 1997–2004 (site D).

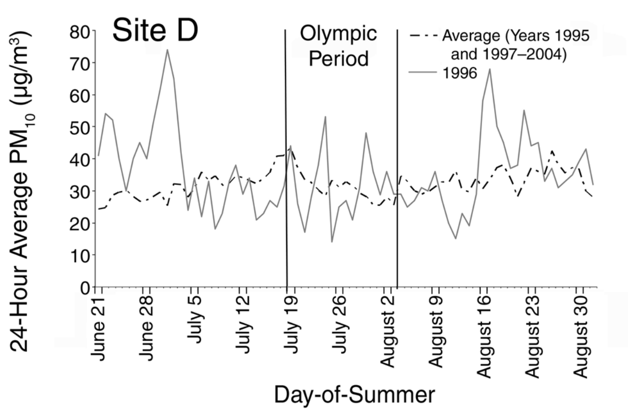


Figure 4. Time-series plots of daily 24-hour average PM_{10} concentration for 1996 and for the average of years 1995 and 1997–2004 (site D).

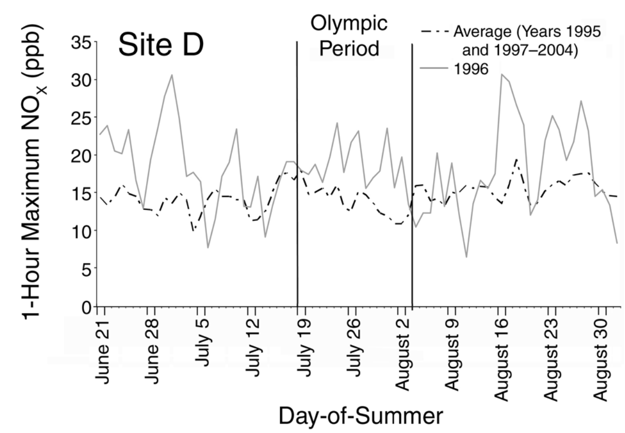


Figure 7. Time-series plots of daily 1-hour maximum NO_x concentration for 1996 and for the average of years 1995 and 1997–2004 (site D).

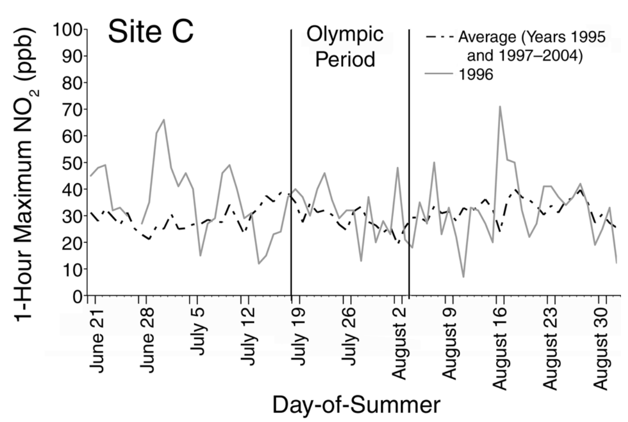


Figure 5. Time-series plots of daily 1-hour maximum NO_2 concentration for 1996 and for the average of years 1995 and 1997–2004 (site C).

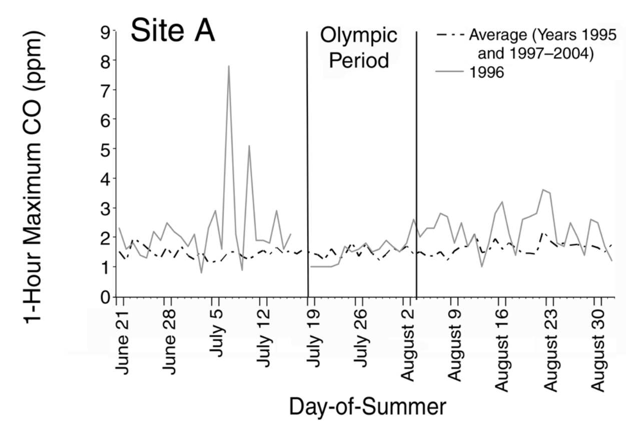


Figure 8. Time-series plots of daily 1-hour maximum CO concentration for 1996 and for the average of years 1995 and 1997–2004 (site A).

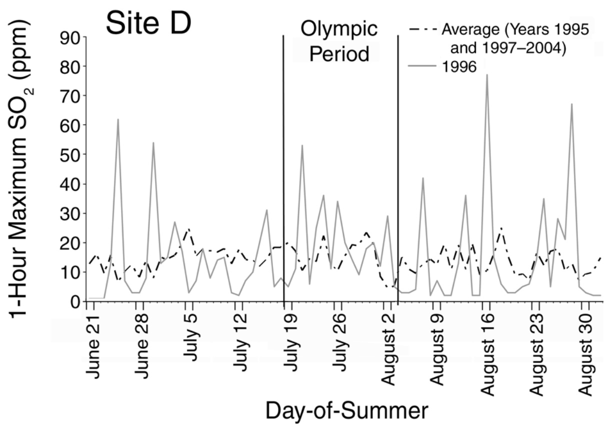


Figure 9. Time-series plots of daily 1-hour maximum SO_2 concentration for 1996 and for the average of years 1995 and 1997–2004 (site D).

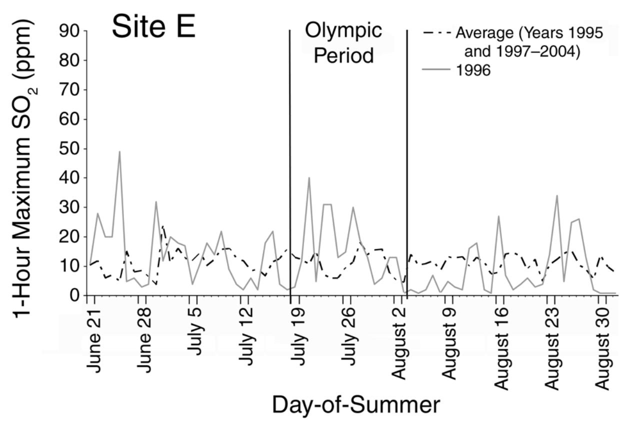


Figure 10. Time-series plots of daily 1-hour maximum SO_2 concentration for 1996 and for the average of years 1995 and 1997–2004 (site E).

Table 4. Mean Weekday Daily Traffic Counts from Available Monitoring Sites Within the Atlanta 5-County Area for the Period During the Olympic Games and for the Baseline Periods Before and After the Olympic Games

Traffic Site by County of Location (Site Number)	Study Periods[a]			*P* Values[b] Comparing Before vs. During	*P* Values[b] Comparing After vs. During
	Baseline Before	During the Games	Baseline After		
Clayton (063-1025)	63,794	65,363	65,831	0.611	0.958
Clayton (063-1085)	25,677	25,427	25,838	0.946	0.861
Clayton (063-1172)	24,163	23,683	24,323	0.822	0.727
Cobb (067-2141)	49,818	50,020	52,692	0.994	0.361
Cobb (067-2623)	36,097	40,014	37,146	**0.003**	**0.042**
DeKalb (089-3132)	24,158	23,655	24,206	0.682	0.632
DeKalb (089-3354)	194,609	209,103	199,384	**0.031**	0.261
DeKalb (089-3438)	15,181	15,312	15,427	0.955	0.966
DeKalb (089-3638)	27,387	28,003	27,777	0.638	0.941
Fulton (121-0124)	36,869	35,626	36,818	0.432	0.455
Fulton (121-0190)	12,402	12,571	12,501	0.816	0.968
Fulton (121-5227)	26,812	26,632	25,984	0.954	0.511
Fulton (121-5450)	78,146	77,046	76,909	0.848	0.997
Fulton (121-5503)	149,560	144,249	147,063	0.291	0.722
Fulton (121-5508)	155,121	155,038	160,417	0.999	0.746
Fulton (121-5538)	135,124	143,052	146,080	0.267	0.820
Fulton (121-5555)	123,276	128,130	121,190	0.334	0.118
Gwinnett (135-0229)	42,232	38,275	39,448	0.055	0.749

[a] 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).

[b] Significant *P* values are bolded.

TRAFFIC COUNTS

Weekday total daily traffic counts for the sites within the 5-county Atlanta area during the Olympic Games period were similar to counts in the Olympic Games baseline periods or even slightly higher for several sites (Table 4). The weekday 1-hour maximum means (morning rush hour, 4 AM–10 AM) from most of the traffic count sites within the 5-county area were lower during the Olympic Games period compared with its baseline periods (Table 5). Weekday 1-hour morning maximum counts from four sites in Fulton and DeKalb County near downtown Atlanta were reduced by about 20%, while the other 14 sites were reduced by 2%–15%. The site with the largest traffic volume actually had a slightly higher 1-hour morning maximum mean traffic count during the Olympic Games period than during the baseline period before the Olympic Games.

ED VISITS

We obtained ED visit information from the SOPHIA database. This database has information on over 10 million ED visits from 1993 through 2004, including information on over 25,000 total ED visits to 12 hospitals during the Olympic Games period and on over 80,000 total ED visits during the Olympic Games baseline periods. Residents of the 5-county Atlanta area accounted for 80% of the total ED visits (including Atlanta residents and nonresidents) during the Olympic Games period compared with 84% during the Olympic Games baseline periods (this difference was due to the influx of nonresidents during the Olympic Games). ED visits for residents of the 5-county area during the Olympic Games period were similar to ED visits during the Olympic Games baseline periods with respect to race, age, payment, and sex (Table 6). These percentages were also similar to those of the 9-year combined

Table 5. Mean Weekday 1-hour Maximum (Morning Rush Hour 4 AM–10 AM) Traffic Counts from Available Monitoring Sites Within the Atlanta 5-County Area for the Period During the Olympic Games and for the Baseline Periods Before and After the Olympic Games

Traffic Site by County of Location (Site Number)	Study Periods[a]			*P* Values[b] Comparing Before vs. During	*P* Values[b] Comparing After vs. During
	Baseline Before	During the Games	Baseline After		
Clayton (063-1025)	3,530	3,295	3,886	0.227	**< 0.001**
Clayton (063-1085)	1,244	1,165	1,280	0.209	**0.042**
Clayton (063-1172)	1,470	1,327	1,507	0.099	**0.038**
Cobb (067-2141)	3,031	2,752	3,175	0.318	0.084
Cobb (067-2623)	2,712	2,651	2,848	0.888	0.316
DeKalb (089-3132)	1,587	1,287	1,597	**0.001**	**< 0.001**
DeKalb (089-3354)	12,294	12,609	13,349	0.821	0.421
DeKalb (089-3438)	1,036	891	1,077	**0.007**	**0.001**
DeKalb (089-3638)	1,716	1,525	1,787	**0.040**	**0.003**
Fulton (121-0124)	2,618	2,299	2,714	**0.036**	**0.004**
Fulton (121-0190)	694	626	665	**0.009**	0.193
Fulton (121-5227)	1,539	1,211	1,455	**< 0.001**	**< 0.001**
Fulton (121-5450)	6,118	4,862	6,251	**< 0.001**	**< 0.001**
Fulton (121-5503)	9,560	7,612	9,908	**< 0.001**	**< 0.001**
Fulton (121-5508)	8,880	8,230	10,662	0.471	**< 0.001**
Fulton (121-5538)	9,524	8,801	10,239	0.374	**0.027**
Fulton (121-5555)	8,944	8,254	8,825	0.240	0.380
Gwinnett (135-0229)	3,349	2,789	2,845	**0.019**	0.954

[a] 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).

[b] Significant *P* values are bolded.

Table 6. Demographic Variables Describing Residents of the Atlanta 5-County Area Who Visited the Emergency Departments of 12 Hospitals for the Period During the Olympic Games and for the Baseline Periods Before and After the Olympic Games

	Study Periods[a]		
	Baseline Before *n* (% of *N*)	During the Games *n* (% of *N*)	Baseline After *n* (% of *N*)
Total residents (*N*)	29,559	17,602	29,248
Race			
Black	7,414 (36.3)	4,458 (36.4)	7,691 (37.5)
White	11,265 (55.2)	6,728 (55.0)	11,074 (53.9)
Hispanic	510 (2.5)	276 (2.3)	507 (2.5)
Other	1,224 (6.0)	774 (6.3)	1,260 (6.1)
Age			
0–1 year	2,448 (8.3)	1,372 (7.8)	2,223 (7.6)
2–18 years	6,596 (22.3)	3,913 (22.2)	6,727 (23.0)
19–64 years	17,430 (59.0)	10,562 (60.0)	17,265 (59.1)
≥ 65 years	3,066 (10.4)	1,747 (9.9)	3,010 (10.3)
Payment			
Medicaid	3,500 (13.6)	2,034 (13.3)	3,276 (12.8)
Self / uninsured	4,752 (18.5)	2,837 (18.6)	4,795 (18.8)
Other / commercial	16,466 (64.1)	9,843 (64.5)	16,572 (65.0)
Workers compensation	953 (3.7)	545 (3.6)	846 (3.3)
Sex			
Female	15,852 (53.6)	9,534 (54.2)	15,461 (52.9)
Male	13,707 (46.4)	8,068 (45.8)	13,785 (47.1)

[a] 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).

Olympic period (data not shown). The total numbers of ED visits to the 12 hospitals by residents of the 5-county Atlanta area were similar in the Olympic Games period (average daily ED visits = 1035) compared with its baseline periods (1056 and 1045 before and after the Olympic Games, respectively). The proportions of ED visits due to respiratory and cardiovascular causes were unchanged in these periods (7% and 2%, respectively; data not shown).

Table 7 lists the mean daily ED visits and standard deviations of case groups from the 12 hospitals for residents of the 5-county Atlanta area, both for the 1996 73-day time series (also used by Friedman and colleagues [2001]) and for the longer, 10-year summer time series. The 73-day time series combines the baseline periods (56 days) and the Olympic period (17 days) in 1996. The 10-year summer time series refers to the same dates in years 1995 through 2004 (including 1996). The 73-day time series has a mean of 79 respiratory ED visits per day and 23 cardiovascular ED visits per day, whereas the longer time series has means of 84 and 26, respectively.

The daily numbers of ED visits for the 12 hospitals within the 5-county area are plotted in Figures 11–16; the daily number of ED visits for the 2 pediatric hospitals is shown in Figures 17 and 18. In these figures, ED visits are plotted for June 21 through September 1 of years 1995 through 2004 with the 1996 data plotted separately. The plots of ED visits for all respiratory disease, upper respiratory infection, and asthma display the typical pattern with the lowest number of ED visits occurring during July and early August.

ED VISIT ANALYSES

Results from the short time-series models for the 12 hospitals in the 5-county area and for the 2 pediatric hospitals in Atlanta are displayed in Table 8. These results are similar to the results of Friedman and colleagues (2001) for pediatric asthma ED visits. Using model 1, reductions in ED visits were observed for the Olympic Games period compared with its baseline periods for pediatric upper respiratory infections (RR = 0.779; 95% CI = 0.632–0.962), for upper respiratory infections in all age groups (0.863; 0.767–0.970), for all respiratory ED visits combined for all ages (0.901; 0.810–1.002), and for all pediatric respiratory ED visits combined (0.798; 0657–0969). No reductions

Table 7. Daily Number of ED Visits to 12 Hospitals by Residents of the Atlanta 5-County Area for the 73-Day Time-Series Period and for the 10-Year Time-Series Period[a]

Case Group	ICD-9 Codes	Time-Series Period (Summers) 73-Day Mean (SD)	10-Year Mean (SD)
All emergency department visits		1047 (66.8)	1130 (129)
All respiratory disease	460–465, 466.0, 480–486, 491–493, 496, 786.09	78.7 (15.4)	84.3 (19.9)
Upper respiratory infections	460–465, 466.0	46.8 (10.9)	49.5 (13.0)
Asthma	493, 786.09	20.2 (5.57)	21.2 (8.11)
Pneumonia	480–486	7.15 (3.11)	9.07 (3.67)
COPD	491, 492, 496	3.68 (2.07)	3.64 (1.97)
All cardiovascular disease	410–414, 427–428, 433–437, 440, 443, 444, 451–453	23.4 (4.21)	26.0 (7.91)
Ischemic heart disease	410-414	8.81 (3.09)	7.78 (3.39)
Dysrhythmias	427	5.67 (1.95)	6.42 (2.62)
Peripheral and cerebrovascular disease	433–437, 440, 443, 444, 451–453	5.11 (2.14)	6.40 (3.13)
Congestive heart failure	428	3.77 (2.02)	5.37 (2.90)
Acute myocardial infarction	410	3.25 (1.77)	3.09 (1.91)
Finger wounds	883.0	18.4 (4.07)	16.6 (4.53)

[a] The 73-day time-series period was from June 21 through September 1, 1996. The ten-year time-series period was from June 21 through September 1 of years 1995–2004 (including 1996).

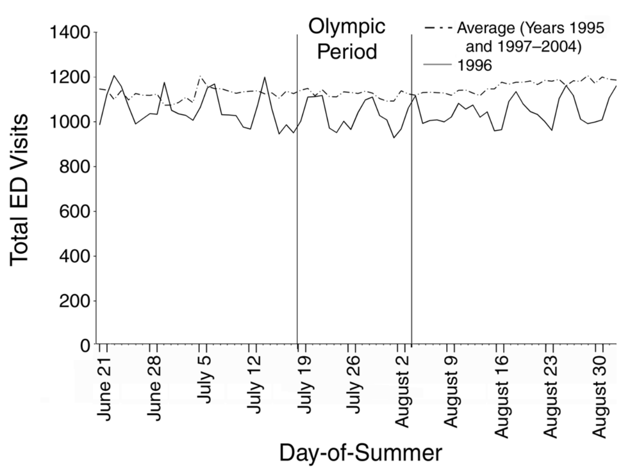


Figure 11. Time-series plots of daily total ED visits to the 12 hospitals in the five-county Atlanta area for 1996 and for the average of years 1995 and 1997–2004.

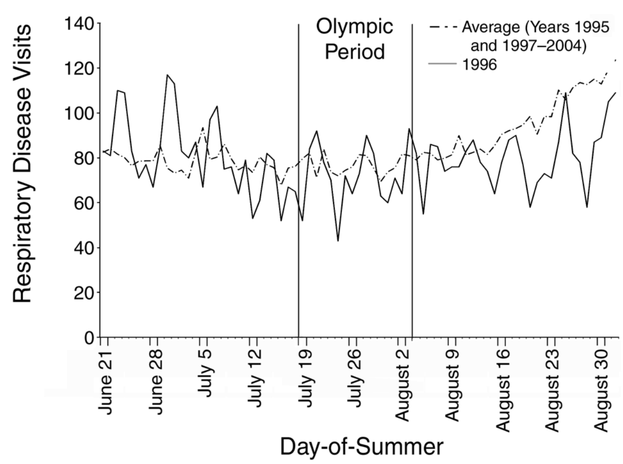


Figure 12. Time-series plots of daily total respiratory ED visits to the 12 hospitals in the five-county Atlanta area for 1996 and for the average of years 1995 and 1997–2004.

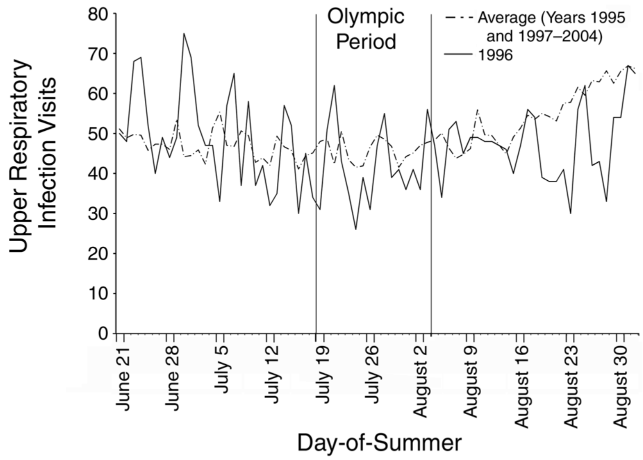


Figure 13. Time-series plots of daily upper respiratory infection ED visits to the 12 hospitals in the five-county Atlanta area for 1996 and for the average of years 1995 and 1997–2004.

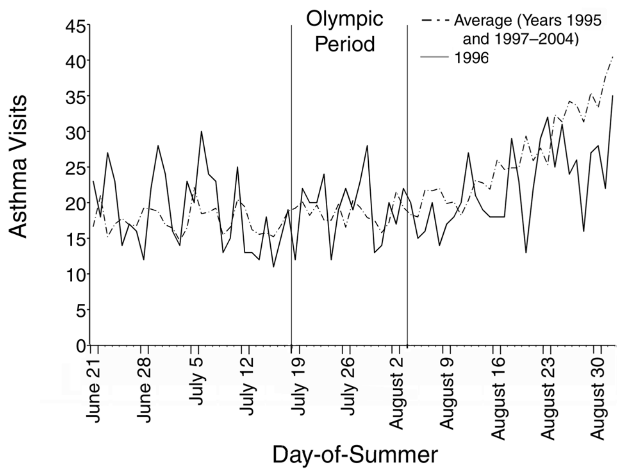


Figure 14. Time-series plots of daily asthma ED visits to the 12 hospitals in the five-county Atlanta area for 1996 and for the average of years 1995 and 1997–2004.

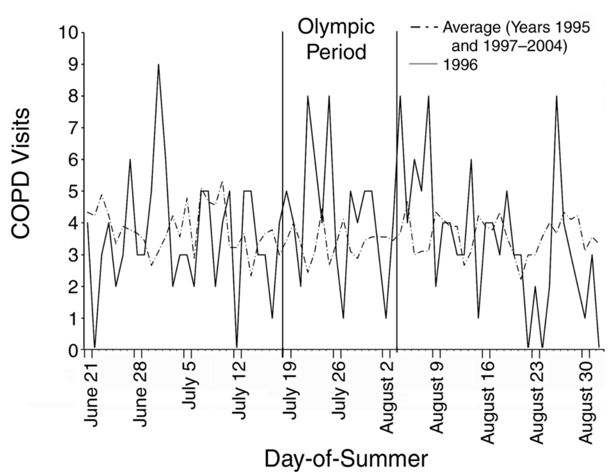


Figure 15. Time-series plots of daily COPD ED visits to the 12 hospitals in the five-county Atlanta area for 1996 and for the average of years 1995 and 1997–2004.

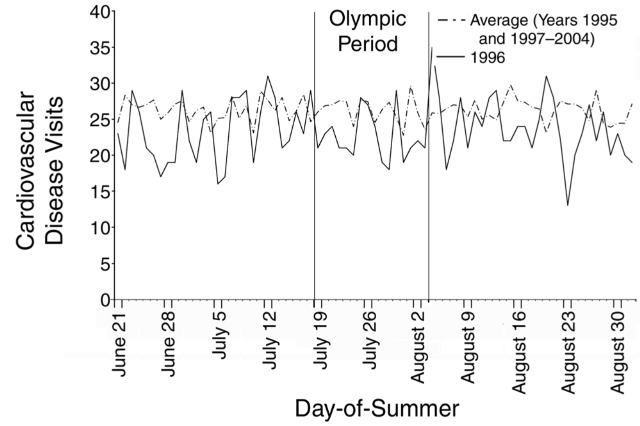


Figure 16. Time-series plots of daily cardiovascular disease ED visits to the 12 hospitals in the five-county Atlanta area for 1996 and for the average of years 1995 and 1997–2004.

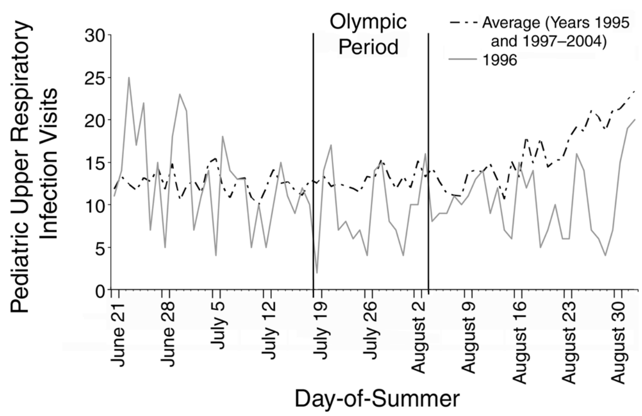


Figure 17. Time-series plots of daily pediatric upper respiratory infection ED visits to two pediatric hospitals in the five-county Atlanta area for 1996 and for the average of years 1995 and 1997–2004.

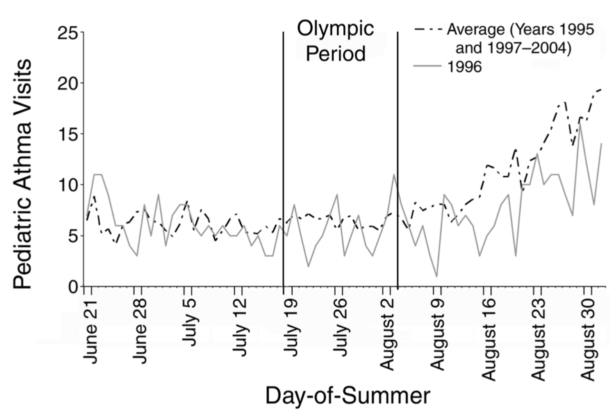


Figure 18. Time-series plots of daily pediatric asthma ED visits to two pediatric hospitals in the five-county Atlanta area for 1996 and for the average of years 1995 and 1997–2004.

Table 8. Relative Risks for ED Visits by Residents of the Atlanta 5-County Area at All 12 Hospitals (All Ages) and Separately at the 2 Pediatric Hospitals for the Period During the Olympic Games[a]

	Model 1[a]	Model 2[b]	Model 3[c]
Case Group	RR (95% CI)	RR (95% CI)	RR (95% CI)
12 Hospitals in 5-County Area (All Ages)			
All respiratory disease	0.901 (0.810–1.002)	0.937 (0.842–1.042)	0.988 (0.883–1.106)
Upper respiratory infections	0.863 (0.767–0.970)	0.893 (0.797–1.001)	0.938 (0.821–1.072)
Asthma	0.940 (0.798–1.107)	1.018 (0.883–1.174)	1.109 (0.957–1.287)
Pneumonia	0.803 (0.617–1.045)	0.813 (0.613–1.078)	0.868 (0.647–1.163)
COPD	1.371 (1.008–1.865)	1.265 (0.929–1.722)	1.163 (0.807–1.676)
All cardiovascular disease	0.994 (0.878–1.125)	0.951 (0.835–1.083)	0.911 (0.794–1.046)
Ischemic heart disease	1.009 (0.825–1.235)	0.961 (0.782–1.180)	0.927 (0.734–1.171)
Dysrhythmias	0.953 (0.747–1.214)	0.972 (0.762–1.239)	0.995 (0.753–1.314)
Peripheral and cerebrovascular disease	0.940 (0.709–1.246)	0.821 (0.640–1.054)	0.719 (0.540–0.957)
Congestive heart failure	1.070 (0.783–1.461)	1.061 (0.722–1.558)	1.039 (0.703–1.536)
Acute myocardial infarction	1.097 (0.797–1.509)	1.051 (0.747–1.479)	1.039 (0.695–1.554)
Finger wounds	0.915 (0.827–1.013)	0.918 (0.823–1.024)	0.937 (0.825–1.064)
2 Pediatric Hospitals			
All respiratory disease	0.798 (0.657–0.969)	0.878 (0.747–1.031)	0.981 (0.816–1.180)
Upper respiratory infections	0.779 (0.632–0.962)	0.837 (0.687–1.019)	0.872 (0.676–1.125)
Asthma	0.953 (0.650–1.399)	1.125 (0.815–1.553)	1.431 (1.048–1.954)
Pneumonia	0.726 (0.407–1.295)	0.705 (0.392–1.270)	0.933 (0.410–1.689)
Finger wounds	1.131 (0.690–1.853)	0.937 (0.572–1.535)	0.823 (0.464–1.457)

[a] Model 1 is the Poisson GEE model where outcome = daily counts, offset = log (total noncase, nonaccidental visits), adjusting for minimum temperature (lag 1) and day-of-week for the period during the Olympic Games (July 19–August 4, 1996).

[b] Model 2 is similar to model 1, but used a shorter time series to better control for time trends (July 1, 1996–August 22, 1996).

[c] Model 3 is similar to model 1, but has added quadratic and cubic terms for day-of-the-time-series to control for time trends.

were observed for pediatric asthma ED visits (0.953; 0.650–1.399). These estimates, particularly the estimates for asthma, were somewhat sensitive to the tighter control for time trends in models 2 and 3. ED visits for COPD increased during the Olympic Games period (1.371; 1.008–1.865); this estimate is unstable owing to low numbers, and therefore is likely to be driven by a few daily ED visits.

Table 9 presents GLM results from the primary analyses of the 12 hospitals in the 5-county area, as well as separate results for the hospitals inside the perimeter highway (closest to downtown Atlanta; hospitals 1–8) and for the 4 hospitals outside the perimeter highway. These are the estimates of the effect of the Olympic Games period (compared with its baseline) adjusting for the effect in other years, meteorologic conditions, and temporal trends. Results from the primary analyses were generally consistent with a null association, indicating that there is no evidence of reduced visits during the Olympic Games period, compared with baseline, after adjusting for the factors above; however, we observed increased ED visits for COPD during the Olympic period (RR = 1.420; 95% CI = 1.048–1.925). ED visits for upper respiratory infections and pneumonia were somewhat reduced during the Olympic Games period, although the 95% CIs were wide and did not exclude a null association. Results from a model with an offset term (log of the daily total noncase, nonaccidental ED visits) were similar to those without the offset in the model (Table 9). Relative risk estimates from the models including data from hospitals inside the perimeter highway were more likely to be less than one, while the estimates from the models including data from hospitals outside the perimeter highway were more likely to be greater than one. However, wide CIs limit the interpretation of these results (Table 9). The increase in ED visits for COPD became stronger in the models including data from hospitals inside the perimeter highway. The results including separate indicator variables for each year were similar to the primary results (results not shown).

Because Friedman and colleagues (2001) reported large reductions in Medicaid claims for pediatric asthma ED visits during the Olympic Games period compared with its baseline periods, we also examined ED visits with Medicaid indicated as the payment. Results from models including data from the two pediatric hospitals for the summers of 1995 through 2004 for all ED visits and for only Medicaid ED visits are presented in Table 10. The results for Medicaid pediatric ED visits were similar to those for all pediatric ED visits. Except for asthma case groups, the results for the pediatric hospitals for the 10-year summer time series are somewhat attenuated (i.e., closer to the null value) compared with those from the 73-day time series (Table 8, Model 1).

Table 9. Relative Risks for ED Visits by Residents of the Atlanta 5-County Area at 12 Hospitals for the Olympic Games Period Compared With the Olympic Games Baseline Periods[a]

	All 12 Hospitals	All 12 Hospitals (Model with Offset[b])	8 Hospitals Inside the Perimeter Highway	4 Hospitals Outside the Perimeter Highway
Case Group	RR (95% CI)	RR (95% CI)	RR (95% CI)	RR (95% CI)
All respiratory disease	1.012 (0.920–1.113)	1.005 (0.897–1.126)	0.964 (0.857–1.085)	1.118 (0.958–1.304)
Upper respiratory infections	0.958 (0.850–1.080)	0.953 (0.831–1.093)	0.881 (0.758–1.024)	1.118 (0.930–1.344)
Asthma	1.112 (0.946–1.306)	1.102 (0.917–1.324)	1.107 (0.916–1.337)	1.123 (0.852–1.481)
Pneumonia	0.933 (0.718–1.213)	0.927 (0.724–1.187)	0.884 (0.659–1.185)	1.100 (0.660–1.831)
COPD	1.420 (1.048–1.925)	1.409 (1.043–1.904)	1.683 (1.157–2.448)	1.021 (0.585–1.780)
All cardiovascular disease	0.996 (0.829–1.195)	0.988 (0.857–1.140)	0.961 (0.804–1.150)	1.099 (0.783–1.541)
Ischemic heart disease	1.076 (0.848–1.365)	1.067 (0.855–1.332)	1.159 (0.893–1.505)	0.804 (0.474–1.365)
Dysrhythmias	0.925 (0.720–1.187)	0.920 (0.728–1.161)	0.760 (0.566–1.022)	1.432 (0.861–2.383)
Peripheral and cerebrovascular disease	0.937 (0.684–1.285)	0.931 (0.701–1.236)	0.891 (0.632–1.255)	1.087 (0.595–1.988)
Congestive heart failure	1.039 (0.729–1.483)	1.030 (0.749–1.416)	0.972 (0.665–1.419)	1.260 (0.653–2.430)
Acute myocardial infarction	1.127 (0.790–1.608)	1.121 (0.801–1.569)	1.197 (0.801–1.790)	0.836 (0.367–1.902)
Finger wounds	0.936 (0.805–1.088)	0.930 (0.793–1.091)	0.989 (0.825–1.186)	0.864 (0.659–1.133)
All injuries	0.998 (0.955–1.043)	0.993 (0.917–1.075)	1.028 (0.973–1.086)	0.951 (0.855–1.057)

[a] Poisson GLMs for the summers (June 21–September 1) of 1995–2004 include an indicator variable for 1996, an indicator variable for the Olympic period (July 19–August 4), the interaction between the year indicator and the Olympic period, minimum temperature (lag 1) and mean dew point (lag 1), day-of-week, and quadratic and cubic terms for day-of-summer.

[b] Offset in Poisson model = log (noncase, nonaccidental visits).

Table 10. Relative Risks for ED Visits by Residents of the Atlanta 5-County Area at 2 Pediatric Hospitals for the Olympic Games Period Compared With the Olympic Games Baseline Periods[a]

	All Pediatric Visits	Medicaid Visits
Case Group	RR (95% CI)	RR (95% CI)
All respiratory disease	0.936 (0.761–1.150)	0.911 (0.623–1.332)
Upper respiratory infections	0.859 (0.659–1.120)	0.836 (0.535–1.306)
Asthma	1.129 (0.855–1.492)	1.132 (0.703–1.823)
Pneumonia	0.896 (0.530–1.515)	0.925 (0.391–2.188)
Finger wounds	1.102 (0.653–1.858)	1.011 (0.259–3.936)
All injuries	1.081 (0.974–1.199)	1.042 (0.740–1.466)

[a] Poisson GLMs for the summers (June 21–September 1) of 1995–2004 include an indicator variable for 1996, an indicator variable for the Olympic period (July 19–August 4), the interaction between the year indicator and the Olympic period, minimum temperature (lag 1) and mean dew point (lag 1), day-of-week, and quadratic and cubic terms for day-of-summer.

DISCUSSION AND CONCLUSIONS

In this study examining the potential impact of reduced pollutant concentrations, we observed little or no evidence of decreased ED visits during the 1996 Summer Olympic Games in Atlanta. When we did observe some evidence of a decreased number of ED visits (e.g., for upper respiratory infections), the results were sensitive to the choice of analytic model and to the method of adjusting for temporal and seasonal trends. We did observe somewhat consistent evidence of an increase in ED visits for COPD during the Olympic Games period, but those results were based on very low numbers of daily ED visits during the summer. Relative risk estimates for some of the smaller case groups (e.g., pneumonia, dysrhythmias, peripheral and cerebrovascular disease, and congestive heart failure) were also less than one, but wide CIs make it difficult to draw a definitive conclusion as to whether or not there was a reduction in these outcomes during the Olympic Games period.

Efforts to reduce vehicular traffic during the Olympic Games were considered to be largely successful (GA EPD 1996; NCHRP 2001). We observed lower traffic counts during this period at several downtown sites. Traffic reductions were observed mostly for the 1-hour maximum traffic counts rather than for the total daily traffic counts, suggesting that residents adjusted work hours to avoid rush-hour congestion (GA EPD 1996; NCHRP 2001). O_3 concentrations were approximately 30% lower during the Olympic Games compared with the four weeks before and after the Olympic Games, and about 20% lower than the mean concentrations for the 11-year combined Olympic period.

Concentrations of PM_{10}, NO_2, and CO were also somewhat lower during the Olympic Games period. PM_{10}, NO_2, and CO concentrations are all directly impacted by emissions from motor vehicles, and O_3 is a secondary formation of primary motor vehicle emissions, suggesting that reduced traffic counts, especially the lower morning rush hour peak counts, may have had an impact on the pollutant concentrations. However, O_3 concentrations were reduced during this period at several sites throughout Georgia and surrounding Southeastern states, indicating that large-scale weather patterns may have played a role, along with the reduced morning traffic counts, in creating the lower pollutant concentrations (NCHRP 2001).

Friedman and colleagues (2001) examined the impact of the Olympic period on pediatric asthma morbidity in Atlanta using Medicaid claims, HMO claims, and ED visits to two pediatric emergency departments. Our results for asthma ED visits at the two pediatric emergency departments for the 73-day time series were similar to those of Friedman and colleagues (2001), with no evidence of a large reduction during the Olympic Games period. Our results for the short time series were sensitive to the choice of baseline period and control for time trend, whereas relative risk estimates for the longer time series were actually suggestive of increased ED visits during the Olympic Games. The more stringent control for time trends was critical during the summer months, when ED visits for asthma and most respiratory conditions were at their lowest. The longer time series have the advantage of examining the comparison of the Olympic period with the baseline period while adjusting for year.

Friedman and colleagues (2001) reported larger reductions for pediatric asthma ED visits in Medicaid claims databases (RR = 0.48; 95% CI 0.44–0.86) than for all pediatric asthma ED visits. In this study we did not observe a greater reduction when we examined Medicaid pediatric asthma ED visits compared with all asthma ED visits. There are several potential reasons for the reductions observed by Friedman and colleagues (2001). The Medicaid claims database they used included asthma acute care events (both ED and urgent care visits). Urgent care visits may include visits for less severe events than an ED database. These less severe events may be more likely to be affected by behavioral changes (such as deciding not to utilize health care services during the Olympic games). In addition, the time-series analyses by Friedman and colleagues (2001) did not adjust for time trend.

These results are somewhat consistent with our previous investigations of air pollution and ED visits in Atlanta, given that in the previous studies we observed associations with multiple pollutants, not just O_3 (Metzger et al. 2004; Peel et al. 2005). We observed increases in respiratory ED visits, particularly for upper respiratory infection and asthma, ranging from 2% to 4% per interquartile range increase in O_3 (Peel et al. 2005). Stronger associations were observed for pediatric asthma and upper respiratory infection compared with those for all age groups or for adults (Peel et al. 2005). ED visits for cardiovascular disease were associated with increased concentrations of PM, CO, and NO_2 (Metzger et al. 2004).

The increased estimated relative risk of ED visits for COPD during the Olympic Games period was unexpected. As with any of our estimates, it may have been due to random error, particularly because the number of ED visits for COPD was very low during the summer of 1996. It may also indicate that the proportion of these visits increased during this period (e.g., people with COPD were less likely than others to leave the area during the Olympic Games). Also, in our previous study of ED visits and air pollution in Atlanta, we reported suggestive associations between increased SO_2 concentrations, which were slightly elevated during the Olympic period, and ED visits for COPD (RR = 1.016; 95% CI = 0.985–1.049) (Peel et al. 2005). However, in the present study we observed that estimates for CO, NO_2, O_3, and PM_{10} were also elevated and that their associations with ED visits for COPD were stronger than the association with SO_2 in our previous analyses. In addition, there is some evidence that COPD has a longer lag structure with respect to air pollution (Peel et al. 2005), suggesting that the increase in ED visits for COPD during the Olympic Games may have been due to higher pollutant concentrations before the Olympic Games.

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 decline in lung function (Downs et al. 2007). These intervention or accountability investigations can be constrained by limited power (due to small reductions in air pollution, small changes in health outcomes, a limited number of days with reduced air pollution, or a combination of these) and inability to control for potential confounders such as temporal trends, changes in behavior and in health care utilization, and widespread epidemics (Varner 2001; HEI 2003; Tolbert 2007; Wittmaack 2007).

This study had several limitations. We evaluated several health endpoints in multiple analyses; thus the issue of multiple testing must be taken into consideration when interpreting the results. This analysis may have had limited power to detect subtle associations owing to low event numbers, insufficient reductions in air pollutant concentrations, and a small number of days in the intervention period. We were also unable to thoroughly evaluate changes in behavior and in health care utilization that were caused by the Olympic Games (e.g., Atlanta residents leaving town or deciding to not use the ED during this period). We examined the percentage of all ED visits made by Atlanta residents, as well as percentages of these Atlanta residents according to race, age, and sex compared with nonresidents making ED visits; these characteristics did not change during the Olympic Games period. We also evaluated multiple referent periods and methods of controlling for time trends and were able to compare the Olympic period effect in 1996 with that in other years.

This project provided an opportunity to examine a short-term effort in Atlanta to reduce traffic, and consequently traffic-related pollution, during the 1996 Summer Olympic Games. It is likely that both large-scale weather patterns and traffic reduction played a role in the reduced air pollutant concentrations observed during the Olympic Games. The results from this study provide little or no evidence of a decrease in ED visits during the Olympic Games in Atlanta. The results were generally sensitive to choice of analytic model and adjustment for time trend, illustrating the difficulties of disentangling the effects of reduced traffic and air pollution from the usual temporal patterns of ED visits during the summer.

This study also demonstrates the limitations and challenges of conducting accountability studies retrospectively, including the need to rely on available data on air pollution, traffic, and health outcomes. Future accountability studies could be designed in advance to answer some of the questions regarding population behavior that were not adequately answered in this study. In addition, the intervention effort during the Summer Olympic Games in Atlanta, even if successful, would not have been sustainable on a long-term basis. Longer and more sustainable intervention efforts may provide insight into the accountability question, while those resulting in larger air pollution reductions may provide additional evidence regarding causal implications of the observed association of air pollution with morbidity and mortality.

ACKNOWLEDGMENTS

We thank Kristi Busico Metzger and Sarah Caesar Tinker for their roles in the emergency department data collection and Lyndsey Darrow for her role in the ambient air quality data collection. We also thank Maggie Clark for her assistance with the report preparation. We are grateful to the participating hospitals, whose staff members devoted many hours of time to the study as a public service.

REFERENCES

Clancy L, Goodman P, Sinclair H, Dockery DW. 2002. Effect of air-pollution control on death rates in Dublin, Ireland: An intervention study. Lancet 360:1210–1214.

Dominici F, Peng RD, Zeger SL, White RH, Samet JM. 2007. Particulate air pollution and mortality in the United States: Did the risks change from 1987 to 2000? Am J Epidem 166:880–888.

Downs SH, Schindler C, Liu L-JS, Keidel D, Bayer-Oglesby L, Brutsche MH, Gerbase MW, Keller R, Künzli N, Leuenberger P, Probst-Hensch NM, Tschopp J-M, Zellweger J-P, Rochat T, Schwartz J, Ackermann-Liebrich U, and the SAPALDIA Team. 2007. Reduced exposure to PM_{10} and attenuated age-related decline in lung function. N Engl J Med 357:2395–2397.

El-Zein A, Nuwayhid I, El-Fadel M, Mroueh S. 2007. Did a ban on diesel-fuel reduce emergency respiratory admissions for children? Sci Total Environ 384:134–140.

Friedman MS, Powell KE, Hutwagner L, Graham LM, Teague WG. 2001. Impact of changes in transportation and commuting behaviors during the 1996 Summer Olympic Games in Atlanta on air quality and childhood asthma. JAMA 285:897–905.

Georgia Environmental Protection Division. October 1, 1996. Improved Air Quality in Atlanta during the 1996 Olympic Summer Games. Georgia Department of Natural Resources, Atlanta, GA.

Health Effects Institute Accountability Working Group. 2003. Assessing health impact of air quality regulations: concepts and methods for accountability research. Health Effects Institute, Cambridge, MA.

Hedley AJ, Wong CM, Thach TQ, Ma S, Lam TH, Anderson HR. 2002. Cardiorespiratory and all-cause mortality after restrictions on sulphur content of fuel in Hong Kong: An intervention study. Lancet 360:1646–1652.

Laden F, Schwartz J, Speizer FE, Dockery DW. 2006. Reduction in fine particulate air pollution and mortality: Extended follow-up of the Harvard Six Cities study. Am J Resp Crit Care Med 173:667–672.

Lwebuga-Mukasa JS, Ayirookuzhi SJ, Hyland A. 2003. Traffic volumes and respiratory health care utilization among residents in close proximity to the Peace Bridge before and after September 11, 2001. J Asthma 40:855–864.

McCullagh P, Nelder JA. 1989. Generalized Linear Models, 2nd Edition. Chapman and Hall, New York, NY.

Metzger KB, Tolbert PE, Klein M, Peel JL, Flanders WD, Todd K, Mulholland JA, Ryan PB, Frumkin H. 2004. Ambient air pollution and cardiovascular emergency department visits. Epidemiology 15:46–56.

National Cooperative Highway Research Program. 2001. Quantifying Air-Quality and Other Benefits and Costs of Transportation Control Measures. National Academy Press, Washington, DC.

National Research Council. 2002. Estimating the Public Health Benefits of Proposed Air Pollution Regulations. National Academy Press. Washington, DC.

Peel JL, Tolbert PE, Klein M, Metzger K, Flanders WD, Todd K, Mulholland J, Ryan PB, Frumkin H. 2005. Ambient air pollution and respiratory emergency department visits. Epidemiology 16:164–174.

Pope CA III. 1989. Respiratory disease associated with community air pollution and a steel mill, Utah Valley. Am J Public Health 79:623–628.

Pope CA III, Dockery DW. 2006. Health effects of fine particulate air pollution: Lines that connect. J Air Waste Manage Assoc 56:709–742.

Pope CA III, Rodermund DL, Gee MM. 2007. Mortality effects of a copper smelter strike and reduced ambient sulfate particulate matter air pollution. Environ Health Perspec 115:679–683.

Pope CA III, Schwartz J, Ransom MR. 1992. Daily mortality and PM_{10} pollution in Utah Valley. Arch Environ Health 47:211–217.

Tolbert PE. 2007. Invited commentary: Heterogeneity of particulate matter health risks. Am J Epidem 166:889–891.

U.S. Environmental Protection Agency. 2004. Air Quality Criteria for Particulate Matter. EPA/600/P-99/002aF-bF. National Center for Environmental Assessment, Research Triangle Park, NC.

U.S. Environmental Protection Agency. 2006. Air quality criteria for ozone and related photochemical oxidants. EPA/600/R- 05/004aF-cF. National Center for Environmental Assessment, Research Triangle Park, NC.

Varner AE. 2001. Automobile traffic, atmospheric pollution, and childhood asthma. JAMA 285:2712–2713.

Wade KS, Mulholland JA, Marmur A, Russell AG, Hartsell B, Edgerton E, Klein M, Waller L, Peel JL, Tolbert PE. 2006. Effects of instrument precision and spatial variability on the assessment of the temporal variation of air pollution in Atlanta, Georgia. J Air & Waste Manage Assoc 56:876–888.

Wittmaack K. 2007. The big ban on bituminous coal sales revisited: Serious epidemics and pronounced trends feign excess mortality previously attributed to heavy black-smoke exposure. Inhal Toxicol 19:343–350.

Zeger SL, Liang KY. 1986. Longitudinal data analysis for discrete and continuous outcomes. Biometrics 42:121–130.

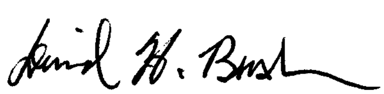
APPENDIX A. HEI Quality Assurance Statement

The conduct of this study was subjected to independent audit by Mr. David Bush of T&B Systems, Inc. Mr. Bush is an expert in quality assurance for air quality monitoring studies and data management. The dates of the audit are listed in the table below with the phase of the study examined.

QUALITY ASSURANCE AUDITS

Date	Phase of Study
March 31–April 1, 2010	The auditor conducted an on-site audit at the Colorado State University in Fort Collins, Colorado. The audit included a review of the project data set utilized in the final report relative to original data sets. Due to IRB restrictions, it was not possible to review the study's raw hospital data. However, the hospital data set has been used in previously published studies, and a summarized data set was available to confirm the report statistics. No data quality related issues were noted, though inconsistencies between the data and several plots and one summary table were identified. All discrepancies were corrected immediately following the audit.

A written report of the audit was provided to the HEI project manager, who transmitted the findings to the Principle Investigator. The quality assurance audit demonstrated that the study was conducted by an experienced team with a high concern for data quality. The report appears to be an accurate representation of the study.



David H. Bush, Quality Assurance Officer

ABOUT THE AUTHORS

Jennifer L. Peel is an assistant professor of epidemiology in the Department of Environmental and Radiological Health Sciences at Colorado State University. She received an M.P.H. and a Ph.D. in epidemiology from the Rollins School of Public Health at Emory University. Her research focuses on the health effects of ambient air pollution and of indoor air pollution from biomass cook stoves.

Mitchel Klein is an associate research professor in the Department of Environmental and Occupational Health in the Rollins School of Public Health at Emory University, with a joint appointment in the Department of Epidemiology. He received a Ph.D. in epidemiology from Emory University. His research focuses on methodologic issues in epidemiology, particularly in air pollution epidemiology.

W. Dana Flanders is a professor in the Department of Epidemiology in the Rollins School of Public Health at Emory University. He received an M.D. from the University of Vermont and a Ph.D. from Harvard University. His research interests include methodologic issues in epidemiology.

James A. Mulholland is a professor in the School of Civil and Environmental Engineering at the Georgia Institute of Technology. He received an M.S. in mechanical engineering from Stanford University and a Ph.D. in chemical engineering from the Massachusetts Institute of Technology. His research includes the study of the formation and control of air pollutants, in particular organic combustion byproducts, and air quality data analysis for use in epidemiologic studies.

Paige E. Tolbert is professor and chair of the Department of Environmental and Occupational Health in the Rollins School of Public Health at Emory University. She received an M.P.H. and a Ph.D. in epidemiology from the University of North Carolina. She has published numerous peer-reviewed articles on various areas of environmental and occupational epidemiology. Currently her research focuses on air pollution and water pollution epidemiology, and she is the principal investigator of the SOPHIA project.

ABBREVIATIONS AND OTHER TERMS

CCS	congestion charging scheme
CI	confidence interval
CO	carbon monoxide
COPD	chronic obstructive pulmonary disease
ED	emergency department
GA EPD	Georgia Environmental Protection Division
GEE	generalized estimating equation
GLM	generalized linear model
HMO	health maintenance organization
ICD-9	*International Classification of Diseases*, Ninth Revision
MSA	metropolitan statistical area
NCHRP	National Cooperative Highway Research Program
NO_x	oxides of nitrogen
NO_2	nitrogen dioxide
O_3	ozone
PM	particulate matter
$PM_{2.5}$	PM ≤ 2.5 µm in aerodynamic diameter
PM_{10}	PM ≤ 10 µm in aerodynamic diameter
RFA	request for applications
RR	relative risk
SO_2	sulfur dioxide
SOPHIA	Study of Particles and Health in Atlanta
U.S. EPA	U.S. Environmental Protection Agency

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 example, it was not clear to what extent normal seasonal patterns in pollutant concentrations or health outcomes may have influenced the results. Health outcomes such as asthma or upper respiratory infections occur less frequently in summer than at other times of the year, and concentrations of pollutants such as O_3 also show fluctuations throughout the year that could have coincided with the timing of the Olympic Games. In addition, it is possible that health care usage during the Olympic Games may have changed because residents may have left the city or otherwise changed the way in which they accessed health care.

Peel and colleagues approached the issue of seasonality in the results by comparing data from 1996 with data during the same summer months in the years before and after the Olympic Games (but without the traffic measures associated with the Olympic Games). They also analyzed weather and pollution data across Georgia and other major urban areas in the Southeastern United States to evaluate whether the reduction in O_3 observed by Friedman and colleagues could be attributed to local, traffic-related interventions or to regional, weather-related phenomena. Furthermore, Peel and colleagues analyzed data from hospitals in downtown Atlanta that were expected to be more directly affected by the changes in traffic patterns than were hospitals outside the downtown area.

Peel and colleagues confirmed that Atlanta experienced a significant decline in O_3 concentrations of 20% to 30% during the Olympic Games period, with a similar decrease (of 30%) in CO concentrations and nonsignificant decreases in concentrations of PM_{10} and NO_2 (of 5%–17%). Importantly, Peel and colleagues found that similar declines in O_3 concentrations were observed throughout Georgia and the Southeastern United States. In its independent review of the study, the HEI Health Review Committee agreed with the investigators that the regional nature of the reduction in O_3 concentrations was due to meteorologic conditions; this factor has made it difficult to assess whether and to what extent the measures to reduce traffic during the Olympic Games contributed to air quality improvements in downtown Atlanta. The Committee noted that it was important that Peel evaluated the other urban areas in the Southeastern United States in addition to rural areas of Georgia, because rural towns may not be comparable to Atlanta in terms of pollution patterns or population and health statistics.

Peel and colleagues reported up to a 20% decline in weekday peak morning traffic counts at four sites in two counties close to downtown Atlanta with 2% to 15% declines at the other sites; these declines were somewhat smaller than that reported by Friedman and colleagues (i.e., 22.5%). In addition, the daily total number of cars commuting into Atlanta was not changed. Thus, it remains unclear whether the measures to improve traffic flow during the Olympic Games had significantly reduced traffic or improved air quality. The Committee noted that there were several sources of uncertainty in the traffic count analysis, including — but not limited to — which vehicle types were affected and how hourly traffic patterns related to concentrations of different air pollutants at the 18 measurement sites. The Committee also noted that when reviewed in retrospect, the traffic measures were quite modest — compared, for example, with traffic controls implemented during the 2008 Summer Olympic Games in Beijing — and may not have been expected to result in substantial air quality changes.

Even though the relative contributions of the traffic measures and meteorology to the observed improvements in air quality in Atlanta during the summer of 1996 cannot be established, it remains important to establish the extent to which such air quality improvements have led to improved health outcomes. However, when Peel and colleagues adjusted their analyses of the Olympic Games period for seasonal trends in air pollutant levels and in health outcomes during the years before and after the Olympic Games, they did not find significant reductions in the number of ED visits for respiratory or cardiovascular health outcomes in adults or children. They reported that the risk estimates often had large CIs, indicating uncertainty in the results, and that they were sensitive to the choice of analytic model. Because the 17-day period of the Olympic Games was short, it is possible that the daily number of ED visits was too low to adequately test the hypothesis that health outcomes would be affected. The only significant result was an unexpected increase in the number of ED visits for COPD; this could have been a random effect due to low daily numbers of ED visits for COPD during the summer. The investigators postulated that there is some evidence that COPD has a longer lag structure with respect to air pollution (Peel et al. 2005); thus, this observation could have represented a delayed effect due to increased air pollution concentrations before the Olympic Games. The Committee, however, suggested that this explanation was unlikely because other daily time-series studies found that the lags between air pollution and COPD exacerbation are not different from those observed with asthma exacerbation (Anderson et al. 1997). Nevertheless, the observation of increased ED visits for COPD does add to the evidence that air pollution-related health impacts were not reduced during the period of the Olympic Games.

This new analysis demonstrates the importance of adequate control for temporal trends. Furthermore, the sensitivity of results to the details of such control shows the importance of a priori determination of the control strategy. When Peel and colleagues analyzed the 73-day period of the Olympic Games and adjacent baseline periods without adjusting for similar trends in surrounding years, they observed reductions in ED visits for upper respiratory infections for all age groups and for pediatric ages that supported the findings by Friedman and colleagues (2001). Using data from two pediatric hospitals, they observed small reductions for pediatric asthma visits similar to what Friedman and colleagues had reported (IR Table 8), although the change was consistent with chance fluctuation and the results were sensitive to tighter controls for time trends. The strongest reduction reported by Friedman and colleagues was from an analysis using a Medicaid database, to which Peel and colleagues did not have access. However, Peel and colleagues did examine ED visits covered by Medicaid and did not observe any changes in the number of ED visits for pediatric asthma or any of the other health outcomes. Some differences between the two studies may have contributed to these differing results. The methods of adjustment for time trends differed between the two studies. Also, Friedman and colleagues used a Medicaid claims database that included both ED visits and acute care events, whereas Peel and colleagues considered only ED visits. Peel has suggested that the potentially less severe acute care events may have been affected by behavioral changes in how Atlanta residents accessed health care during the Olympic Games period; although this is plausible, no evidence is adduced either way.

The principles underlying a comprehensive evaluation of a short-term intervention such as traffic management during the Olympic Games period are difficult to apply in practice, for three main reasons. First, it is necessary to establish that the measures to improve traffic flow during the period of the Olympic Games were effective in reducing traffic, and that such a reduction led to improved air quality during that period. As this study demonstrates, this may be difficult. In this respect, the availability of spatial as well as temporal control periods is crucial; in the present case the observation that O_3 concentrations were low throughout the Southeastern United States casts doubt on the influence of the Atlanta-specific changes in traffic management. Second, it is necessary to establish an association between the intervention and a change in health outcomes. Here is it vital to have an appropriate control structure, and this study demonstrates the importance of employing robust controls for seasonality. Ideally, it would be a further advantage to include contemporaneous spatial control data. Third, even if associations between the period of the Olympic Games and changes in air quality and health outcomes could be established statistically, there would remain the question of causality. A temporary change in the use of hospital services could be explained by other factors such as changes in population numbers or behavior in accessing health care.

At the outset of the study, the investigators had to make choices about which periods to analyze. Because the 17-day period of the Olympic Games was rather short, it would be important to choose appropriate periods before and after the Olympic Games for comparison. Like Friedman and colleagues, Peel and colleagues chose to analyze 28 days before and 28 days after the Olympic Games; they also conducted a sensitivity analysis with 14-day baseline periods (and reported that the results were somewhat sensitive to tighter control for time trends). The 14-day period is more comparable to the Olympic Games period but reduces the overall number of days analyzed and thereby the power of the study. A baseline period longer than 4 weeks would increase the number of days included in the analyses, but also possibly introduce other trends, such as changes in weather or people's behavior (for example, vacation in July and August but back to school in early September). A similar set of choices was faced by Kelly and colleagues, who analyzed different periods (weeks, months, or years) before and after implementation of the CCS in London (Kelly et al. 2010; Tonne et al. 2010); their final comparison relied on comparing two years before and after the intervention, as this was most robust to weather variability and seasonal factors (Atkinson et al. 2009).

To address seasonality, Peel and colleagues analyzed data from the years before and after the Olympic Games. Initially, they used two approaches. The first approach was to analyze only the 17-day Olympic periods in the years before and after the Olympic Games. The second approach was to analyze data from the entire year and use cubic splines to adjust for seasonality in the data. However, analyzing the entire year might introduce more variability due to different pollutant concentrations and health outcome trends — such as influenza epidemics — in fall and winter compared with summer, which might unnecessarily complicate the analyses. In communications with the HEI Health Review Committee, it was concluded that the first approach should include the baseline periods to properly adjust for seasonality and that the second approach might overadjust for seasonality because the splines are difficult to reconcile with the assumed step function in air quality changes. Thus, the Committee recommended comparing the 73-day summer period in 1996 with the same 73-day period in the years before and after the Olympic Games, which is the approach presented in the Investigators' Report.

Although well-designed studies can provide insight into the effectiveness of regulatory decisions, interpretation of results can be difficult when the changes in pollutant concentrations or in health outcomes are small, or when there are simply not enough events to conduct a meaningful analysis. A detailed discussion of the general challenges that researchers face in conducting such studies is included in HEI's interim evaluation of its Accountability Research Program (van Erp and Cohen 2009). The study by Peel and colleagues was designed carefully, but it was constrained by the short duration of the intervention, the small reductions in air pollution concentrations, the low daily numbers of ED visits, difficulty of isolating the effects of an intervention from usual temporal patterns in health care usage, and a lack of control areas. Although Peel and colleagues examined important potential confounders that were not addressed in the study by Friedman and colleagues, the retrospective nature of the study limited the investigators' ability to evaluate behavioral changes (e.g., Atlanta residents potentially leaving the city during the Olympic period) that may have influenced the results.

Evaluation of traffic congestion measures in London faced similar challenges, although in the context of an intervention with a different (long-term) time-frame: short-term changes in pollution concentrations were obscured by coincidental changes in weather patterns, the inner-city area affected by the intervention was small, and reductions in the numbers of cars entering the inner city were offset by increased numbers of buses and taxis (Kelly et al. 2010). However, when longer periods of two years before and after the intervention were compared, more robust changes in air quality were observed between the CCS area and the control area (outer London). This example illustrates the importance of using a contemporaneous control area, a dimension that was lacking in the Atlanta study. Although it is possible to calculate theoretical health benefits under different traffic-intervention scenarios based on predicted air quality changes and pre-existing health risk estimates, as was done for the London CCS (Tonne et al. 2008), it is important to evaluate, if possible, whether the predicted improvements actually occurred (Kelly et al. 2010; Tonne et al. 2010). It is also important to measure the air quality changes because these do not necessarily correspond to those predicted by models. In the case of the London CCS, for example, the observed increases in NO_2 and O_3 were not predicted; this finding illustrates the point that changes in health outcomes cannot be assumed to be entirely beneficial (Atkinson et al. 2009).

SUMMARY

Peel and colleagues successfully conducted an extensive evaluation of health outcomes associated with air quality changes during the Olympic Games in Atlanta that critically expanded the initial evaluation by Friedman and colleagues (2001). Peel and colleagues used more detailed information on traffic, air quality, and weather in the Southeastern United States and evaluated a much wider range of health outcomes in different age groups. They carefully conducted a number of sensitivity analyses to adjust for seasonal variation in air quality and in health outcomes, evaluating effect estimates based on different periods surrounding the Olympic Games and comparing them with estimates in surrounding years.

Among their many useful findings, the investigators showed that morning peak-hour traffic counts were reduced during the Olympic Games period in 1996, owing to the planned intervention to reduce traffic, although total daily traffic in Atlanta was not reduced. They also confirmed that O_3 concentrations were reduced by 20% to 30% during the Olympic Games compared with 4-week periods before and after the Olympic Games. However, concurrent reductions in O_3 concentrations were observed in other areas in Georgia and other urban areas in the Southeastern United States. The regional nature of the reduction in O_3 concentrations has made it difficult to assess the extent to which the measures to reduce traffic during the Olympic Games may have contributed to O_3 reductions in downtown Atlanta and suggests that regional meteorology was an important factor. When Peel and colleagues adjusted their analyses of the Olympic Games period in 1996 for seasonal trends in air pollutant levels and health outcomes during the years before and after the Olympic Games, they did not find significant reductions in the numbers of ED visits for respiratory or cardiovascular health outcomes in adults or in children. When they analyzed the 73-day period of the Olympic and adjacent baseline periods without adjusting for similar trends in surrounding years, they observed reductions in ED visits for upper respiratory infections for all age groups and for the pediatric age group, but they could not reproduce the observation by Friedman and colleagues (2001) that the number of pediatric emergency care visits for asthma was reduced during the Olympic Games period. This study illustrates the importance of evaluating appropriate time windows surrounding interventions, properly adjusting for seasonal and other trends that may influence the results, and using control areas. Evaluation of short-term air quality interventions remains challenging, especially if the period of the intervention is only 17 days, because changes in meteorologic conditions could easily overwhelm any changes that may be due to the intervention. More broadly, this study emphasizes the importance of examining the full chain of events that might result from any such intervention — for example, asking first whether an intervention actually reduced traffic, then asking whether that reduction in traffic resulted in improved air quality, and then finally examining whether any observed improvements in air quality actually resulted in health improvements.

REFERENCES

Anderson HR, Spix C, Medina S, Schouten JP, Castellsague J, Rossi G, Zmirou D, Touloumi G, Wojtyniak B, Ponka A, Bacharova L, Schwartz J, Katsouyanni K. 1997. Air pollution and daily admissions for chronic obstructive pulmonary disease in 6 European cities: Results from the APHEA project. Eur Respir J 10:1064–1071.

Anderson HR, Atkinson RW, Peacock JL, Marston L, Konstantinou K. 2004. Meta-analysis of time series studies and panel studies of particulate matter (PM) and ozone (O_3). Report of a WHO Task Group. World Health Organization. Copenhagen. Available from *www.euro.who.int/document/e82792.pdf*.

Atkinson RW, Barratt B, Armstrong B, Anderson HR, Beevers SD, Mudway IS, Green D, Derwent RG, Wilkinson P, Tonne C, Kelly FJ. 2009. The impact of the congestion charging scheme on ambient air pollution concentrations in London. Atmos Environ 43:5493–5500.

Bell ML, McDermott A, Zeger SL, Samet JM, Dominici F. 2004. Ozone and short-term mortality in 95 US urban communities, 1987–2000. JAMA 292:2372–2378.

Bergman P, Grjibovski AM, Hagströmer M, Patterson E, Sjöström M. 2010. Congestion road tax and physical activity. Am J Prev Med. 38:171–177.

Dijkema MBA, van der Zee SC, Brunekreef B, van Strien RT. 2008. Air quality effects of an urban highway speed limit reduction. Atmos Environ 42:9098–9105.

Friedman MS, Powell KE, Hutwagner L, Graham LM, Teague WG. 2001. Impact of changes in transportation and commuting behaviors during the 1996 Summer Olympic Games in Atlanta on air quality and childhood asthma. JAMA 285:897–905.

Hedley AJ, Wong CM, Thach TQ, Ma S, Lam TH, Anderson HR. 2002. Cardiorespiratory and all-cause mortality after restrictions on sulphur content of fuel in Hong Kong: An intervention study. Lancet 360:1646–1652.

HEI Panel on the Health Effects of Traffic-Related Air Pollution. 2010. Traffic-Related Air Pollution: A Critical Review of the Literature on Emissions, Exposure, and Health Effects. Special Report 17. Health Effects Institute, Boston, MA.

Hugosson MB, Sjöberg A, Byström C. 2006. Facts and results from the Stockholm trial. Technical Report. Stockholm Congestion Charging Secretariat. Stockholm, Sweden.

Jerrett M, Burnett RT, Pope CA, Ito K, Thurston G, Krewski D, Shi YL, Calle E, Thun M. 2009. Long-Term Ozone Exposure and Mortality. N Engl J Med 360:1085–1095.

Katsouyanni K, Samet JM, Anderson H, Atkinson R, Le Tertre A, Medina S, Samoli E, Touloumi G, Burnett RT, Krewski D, Ramsay T, Dominici F, Peng RD, Schwartz J, Zanobetti A. 2009. Air Pollution and Health: A European and North American Approach. Research Report 142. Health Effects Institute, Boston, MA.

Kelly FJ, Anderson HR, Armstrong B, Atkinson RW, Barratt B, Beevers SD, Derwent RG, Green D, Mudway IS, Wilkinson P. 2010. An Assessment of the Impact of the Congestion Charging Scheme on Air Quality in London. Health Effects Institute, Boston, MA. In press.

Krewski D, Jerrett M, Burnett RT, Ma R, Hughes E, Shi Y, Turner M, Pope III CA, Thurston G, Calle EE, Thun MJ. 2009. Extended Follow-Up and Spatial Analysis of The American Cancer Society Study Linking Particulate Air Pollution and Mortality. Research Report 140. Health Effects Institute, Boston, MA.

Metzger KB, Tolbert PE, Klein M, Peel JL, Flanders WD, Todd K, Mulholland JA, Ryan PB, Frumkin H. 2004. Ambient air pollution and cardiovascular emergency department visits. Epidemiology 15:46–56.

Peel JL, Tolbert PE, Klein M, Metzger KB, Flanders WD, Todd K, Mulholland JA, Ryan PB, Frumkin H. 2005. Ambient air pollution and respiratory emergency department visits. Epidemiology 16:164–174.

Pope CA III, Burnett RT, Thun MJ, Calle EE, Krewski D, Ito K, Thurston GD. 2002. Lung cancer, cardiopulmonary mortality, and long-term exposure to fine particulate air pollution. JAMA 287:1132–1141.

Samet JM, Zeger SL, Dominici F, Curriero F, Coursac I, Dockery DW, Schwartz J. 2000. The National Morbidity, Mortality, and Air Pollution Study, Part II: Morbidity and

Mortality from Air Pollution in the United States. Research Report 94. Health Effects Institute, Boston, MA.

Schwela D. 2000. Air pollution and health in urban areas. Rev Environ Health 15:13–42.

Tonne C, Beevers S, Armstrong BG, Kelly F, Wilkinson P. 2008. Air pollution and mortality benefits of the London Congestion Charge: spatial and socioeconomic inequalities. Occup Environ Med 65:620–627.

Tonne C, Beevers S, Kelly F, Jarup L, Wilkinson P, Armstrong BG. 2010. An approach for estimating the health effects of changes over time in air pollution: an illustration using cardio-respiratory hospital admissions in London. Occup Environ Med. Epub ahead of print. Available from *www.ncbi.nlm.nih.gov/pubmed/19914909.* Accessed April 8, 2010.

van Erp AM, Cohen AJ. 2009. HEI's Research Program on the Impact of Actions to Improve Air Quality: Interim Evaluation and Future Directions. Communication 14. Health Effects Institute, Boston, MA.

Wang L, Hao J, He K, Wang S, Li J, Zhang Q, Streets DG, Fu JS, Jang CJ, Takekawa H, Chatani S. 2008. A modeling study of coarse particulate matter pollution in Beijing: Regional source contributions and control implications for the 2008 Summer Olympics. J Air Waste Manag Assoc 58:1057–1069.

Yuval, Flicstein B, Broday DM. 2008. The impact of a forced reduction in traffic volumes on urban air pollution. Atmos Environ 42:428–440.

ACKNOWLEDGMENTS

The Health Review Committee thanks the ad hoc reviewers for their help in evaluating the scientific merit of the Investigators' Report. The Committee is also grateful to Maria Costantini for her oversight of the study, to Annemoon van Erp and Kelly Pitts for their assistance in preparing its Critique, to Carol Moyer for science editing of this Report and its Critique, to Ruth Shaw for its composition, and to Fred Howe, Bernard Jacobson, and Flannery McDermott for their roles in preparing this Research Report for publication.

RELATED HEI PUBLICATIONS: PARTICULATE MATTER

Number	Title	Principal Investigator	Date*
Research Reports			
142	Air Pollution and Health: A European and North American Approach (APHENA)	K. Katsouyanni	2009
140	Extended Follow-Up and Spatial Analysis of the American Cancer Society Study Linking Particulate Air Pollution and Mortality	D. Krewski	2009
139	Effects of Long-Term Exposure to Traffic-Related Air Pollution on Respiratory and Cardiovascular Mortality in the Netherlands: the NLCS-AIR Study	B. Brunekreef	2009
131	Characterization of Particulate and Gas Exposures of Sensitive Subpopulations Living in Baltimore and Boston	P. Koutrakis	2005
130	Relationships of Indoor, Outdoor, and Personal Air (RIOPA)		
	Part I. Collection Methods and Descriptive Analyses	C.P. Weisel	2005
	Part II. Analyses of Concentrations of Particulate Matter Species	B.J. Turpin	2007
127	Personal, Indoor, and Outdoor Exposures to $PM_{2.5}$ and Its Components for Groups of Cardiovascular Patients in Amsterdam and Helsinki	B. Brunekreef	2005
124	Particulate Air Pollution and Nonfatal Cardiac Events		2005
	Part I. Air Pollution, Personal Activities, and Onset of Myocardial Infarction in a Case–Crossover Study	A. Peters	
	Part II. Association of Air Pollution with Confirmed Arrhythmias Recorded by Implanted Defibrillators	D. Dockery	
123	Time-Series Analysis of Air Pollution and Mortality: A Statistical Review	F. Dominici	2004
99	A Case–Crossover Analysis of Fine Particulate Matter Air Pollution and Out-of-Hospital Sudden Cardiac Arrest	H. Checkoway	2000
98	Daily Mortality and Fine and Ultrafine Particles in Erfurt, Germany *Part I.* Role of Particle Number and Particle Mass	H-E. Wichmann	2000
97	Identifying Subgroups of the General Population That May Be Susceptible to Short-Term Increases in Particulate Air Pollution: A Time-Series Study in Montreal, Quebec	M.S. Goldberg	2000
95	Association of Particulate Matter Components with Daily Mortality and Morbidity in Urban Populations	M. Lippmann	2000
94	National Morbidity, Mortality, and Air Pollution Study		
	Part I. Methods and Methodologic Issues	J.M. Samet	2000
86	Statistical Methods for Epidemiologic Studies of the Health Effects of Air Pollution	W. Navidi	1999

Continued

* *Reports published since 1998.*
Copies of these reports can be obtained from the Health Effects Institute and many are available at www.healtheffects.org.

RELATED HEI PUBLICATIONS: PARTICULATE MATTER

Number	Title	Principal Investigator	Date*
Special Reports			
17	Traffic-Related Air Pollution: A Critical Review of the Literature on Emissions, Exposure, and Health Effects		2010
	Revised Analyses of Time-Series Studies of Air Pollution and Health		2003
	Reanalysis of the Harvard Six Cities Study and the American Cancer Society Study of Particulate Air Pollution and Mortality		2000
HEI Communications			
14	HEI's Research Program on the Impact of Actions to Improve Air Quality: Interim Evaluation and Future Directions		2009
11	Assessing the Health Impact of Air Quality Regulations: Concepts and Methods for Accountability Research		2003
8	The Health Effects of Fine Particles: Key Questions and the 2003 Review (Report of the Joint Meeting of the EC and HEI)		1999
HEI Research Program Summaries			
	Research on Diesel Exhaust and Other Particles		2003
	Research on Particulate Matter		1999
HEI Perspectives			
	Understanding the Health Effects of Components of the Particulate Matter Mix: Progress and Next Steps		2002
	Airborne Particles and Health: HEI Epidemiologic Evidence		2001

** Reports published since 1998.*
Copies of these reports can be obtained from the Health Effects Institute and many are available at www.healtheffects.org.

HEI BOARD, COMMITTEES, and STAFF

Board of Directors

Health Research Committee

HEI BOARD, COMMITTEES, and STAFF

Health Review Committee

Officers and Staff

HEALTH
EFFECTS
INSTITUTE

101 Federal Street, Suite 500
Boston, MA 02110, USA
+1-617-488-2300
www.healtheffects.org

RESEARCH
REPORT

Number 148
April 2010