STATEMENT

Synopsis of Research Report 190

HEALTH EFFECTS INSTITUTE

The Effects of Policy-Driven Air Quality Improvements on Children's Respiratory Health

INTRODUCTION

The report by Dr. Frank Gilliland and colleagues, *The Effects of Policy-Driven Air Quality Improvements on Children's Respiratory Health*, is the latest in a series of studies funded as part of HEI's accountability research program. Launched in 2001, the program has supported a number of studies aimed at evaluating whether regulatory and other actions taken to improve air quality have resulted in the intended improvements in air quality, population exposures, and health outcomes. Gilliland and colleagues' study addressed a critical issue: assessment of the effects of regulatory actions taken at both a national and a regional level that have been implemented over multiple years.

The investigators built on their earlier work in the Children's Health Study (CHS), which has for more than 20 years been evaluating associations between levels of several major outdoor pollutants and the respiratory health of children who live in Southern California. The CHS has shown that long-term exposure of children to elevated levels of outdoor air

What This Study Adds

- Gilliland and colleagues addressed a key public health issue: Do regulations enacted to decrease emissions of major outdoor air pollutants result in long-term decreases in levels of the targeted pollutants and in improvements in the health of the exposed population?
- A major strength of the study was that it used data on $PM_{2.5}$, PM_{10}, NO_2, O_3 levels, and lung function and respiratory symptoms collected over 20 years as a part of the Children's Health Study, covering three cohorts living in Southern Californian communities; these communities had different air pollution characteristics allowing for cross-cohort comparisons.
- Nearly 20 major policy actions were implemented in Southern California from 1993 to 2012 to reduce pollution from transportation and other sources. Emissions and ambient levels of pollutants decreased during that period, but the large number of regulations made it difficult to link any specific action to an improvement in air quality.
- Decreases in long-term community-level averages of pollutants — particularly NO_2 and $PM_{2.5}$ — were associated with increased growth of children's lung function across the cohorts. Decreases in levels of NO_2, $PM_{2.5}$, PM_{10}, and O_3 were associated with decreased prevalence of respiratory symptoms (bronchitis, cough, and phlegm), particularly in children with asthma.
- The Review Committee agreed with the major findings of this study, which were that emissions and pollutant levels decreased and the children's health status improved. There was, however, variability in the relationship between pollution decreases and changes in lung function and respiratory symptom measures among the communities, suggesting that unexplored between- and within-community factors could be important. The Committee also pointed to other areas where future research may be fruitful.
- These findings are important in indicating the potential for notable health benefits from the decreasing levels of major outdoor pollutants resulting from public policy measures.

This Statement, prepared by the Health Effects Institute, summarizes a research project funded by HEI and conducted by Dr. Frank Gilliland at the University of Southern California, Los Angeles, and colleagues. The complete report, *The Effects of Policy-Driven Air Quality Improvements on Children's Respiratory Health* (© 2017 Health Effects Institute), can be obtained from HEI or our Web site (see last page).

pollution has adverse effects on the development of their lung function and that exposure to outdoor pollution in Southern California was associated with increased symptoms of airway disease in children.

Over the course of the CHS, the United States Environmental Protection Agency and regional agencies (including the California Air Resources Board) put in place many different regulations intended to curb emissions and reduce pollutant levels, and the levels of many outdoor pollutants have decreased in Southern California over the time period. Thus, the first goal of the current study was to identify the major air quality regulations for mobile, stationary, and area source emissions, enforced both nationally and in California over the 20 years between 1993 and 2012, and link them to improvements in air quality in Southern California communities. The second goal was to explore associations between the decreases in long-term levels of major outdoor pollutants and improvements in children's respiratory health over the same time period.

The focus of the respiratory health aspects of the current study were lung growth and symptoms of respiratory conditions: the investigators assessed how the observed decreases in pollutant levels affected the development of lungs in children during their teenage years, a crucial period for lung development. After the teenage years, there is little growth in lung size or capacity, and lung size at age 18 is a predictor of respiratory and cardiovascular morbidity and mortality in later life. The investigators also asked how the long-term changes in pollutant levels affected symptoms of respiratory conditions in children between ages 9 and 18. Outdoor pollutants affect children with asthma more than children without asthma, and the incidence of asthma has grown over the last several decades.

APPROACH

Study Participants and Health Data

The goal of the study was to evaluate changes in outdoor pollutant levels and in participants' lung function and respiratory symptoms in communities that had data for children of the same ages across three cohorts recruited at different times over the course of the CHS (1992–1993 for Cohort C, 1995–1996 for Cohort D, and 2002–2003 for Cohort E). Participants were drawn from five CHS communities for lung-function analysis and eight CHS communities for the respiratory symptoms analysis — the same five communities in the lung-function analysis plus three others. Continuous pollution measurements had been collected in these eight communities over the 20 years of the CHS.

The principal markers of lung function used in the lung-growth substudy were forced expiratory volume in the first second of exhalation (FEV_1) and forced vital capacity (FVC). FEV_1 and FVC were measured annually for children between the ages of 10 and 18 in Cohorts C and D and every 2 years (at approximate ages 11, 13, and 15) in Cohort E. The investigators then calculated the 4-year growth in FEV_1 and FVC for the children in all three cohorts (N = 2,120) between the ages of 11 and 15. Using data from the children for whom they had data at both ages 11 and 15 in all three cohorts (n =1,585), they also calculated the percentage of children in each cohort who had clinically important deficits in FEV_1 and FVC using three cutoffs (<90%, 85%, or 80% of expected function for that age), taking into account such factors as ethnicity, sex, height, and body mass index.

From responses to annual questionnaires, the investigators also collected information for the respiratory symptoms substudy about each child's asthma status and respiratory symptoms over the previous 12 months. Data were analyzed from all children from ages 9 to 18 years old (N = 4,602) in the eight communities in all three cohorts. The questionnaires also provided other relevant information, including age, sex, race, ethnic background, insurance coverage, and education of parents; prior and current health conditions; and other potential sources of pollutant exposure in the home, such as environmental tobacco smoke and the presence of a dog or cat.

Exposure Assessment

Beginning in 1994 for the original 12 CHS communities, the investigators collected measurements at one central site in each community of levels of nitrogen dioxide (NO_2), particulate matter (PM) equal to or less than 2.5 microns in aerodynamic diameter ($PM_{2.5}$), PM equal to or less than 10 microns in aerodynamic diameter (PM_{10}), and ozone (O_3). The investigators calculated daily and monthly averages for each pollutant and calculated an annual average in each community from the monthly averages. For the lung-function substudy, the investigators calculated the mean air pollutant concentrations for each community over the relevant 4-year exposure period for each cohort. In the respiratory symptoms substudy, the investigators used community-specific annual averages of PM_{10}, $PM_{2.5}$, NO_2, and O_3 to compute cohort-specific mean levels for the relevant period of follow-up (9 years in Cohorts C and D, 10 years

for Cohort E). Because asthma symptoms were defined in the year before the children responded to the questionnaire, the investigators used a 1-year lagged annual average for each pollutant in the symptom substudy.

Statistical Methods

The main goal of the lung-function substudy was to estimate the association of individual pollutants with the growth of lung function in children between the ages of 11 and 15, as measured by FEV_1 and FVC. Because lung-function growth is nonlinear, the investigators used a linear spline model they had previously developed, with knots at ages 12, 14, and 16, to construct growth curves of lung function over the entire age range of the cohorts (approximately 9 to 19 in Cohorts C and D and 10 to 16 in Cohort E) in the five communities in which they had measured children's lung function. The model included adjustments for factors such as sex, race, ethnicity, height, and body mass index.

To determine whether the changes in the proportion of children with clinically important deficits in FEV_1 and FVC at age 15 were associated with long-term changes in air quality, Gilliland and colleagues used data from all three cohorts to develop linear prediction models for FEV_1 and FVC that included adjustments for factors that included age, sex, race and ethnicity, height, and body mass index. They then used a logistic regression model to test for temporal trends in the proportion of children with low lung function.

To estimate associations between cohort- and community-specific levels of individual pollutants and respiratory symptoms, the investigators used multilevel models they had developed previously. Data were analyzed from all children (N = 4,602) from ages 9 to 18 years old in the eight communities in all three cohorts. Sensitivity analyses included owning a dog or cat and exposure to secondhand smoke in the home.

Regulations and Emissions

Gilliland and colleagues identified nearly 20 major policies introduced at the national or California-wide level at various times between 1985 and 2012 that they predicted would have major impacts on air pollution. The investigators then used information from the California Air Resources Board and the South Coast Air Quality Management District, agencies responsible for air pollution regulations affecting Southern California, to make "backcasted" estimates of air pollutant emissions in multiple categories for oxides of nitrogen (NO_x), $PM_{2.5}$, PM_{10}, oxides of sulfur (SO_x), and reactive organic gases (ROG). They made estimates for 1993 and 2011 in various parts of Southern California (the Southern California Basin around Los Angeles as well as Santa Barbara and San Diego counties).

KEY RESULTS

Total emissions of NO_x, ROG, $PM_{2.5}$, PM_{10}, and SO_x and emissions in nearly all major categories (stationary, area-wide, on-road and other mobile sources) decreased in Southern California between 1993 and 2012. The largest decrease was in NO_x and ROG emissions from on-road motor vehicles.

Annual levels of individual pollutants, particularly NO_2 and $PM_{2.5}$, generally decreased over the course of the study, with the lowest multiyear average levels recorded in Cohort E, the most recently recruited cohort. However, the investigators noted that the large number of air quality policies put in place by national and state agencies made it difficult to link any specific action to any specific improvements in air quality.

The two principal health findings of the study were that, first, decreases in multiyear average levels of outdoor pollutants — particularly NO_2 and $PM_{2.5}$ — were associated with cross-cohort improvements in the growth of children's lung function; in Cohort E, with the lowest overall levels of outdoor pollutants fewer children had clinical deficits in FEV_1 and FVC at age 15 than did children in the other two cohorts. Second, decreases in the levels of outdoor pollutants (NO_2, $PM_{2.5}$, PM_{10}, and O_3) were associated with cross-cohort decreases in the prevalence of symptoms of respiratory conditions in children at ages 10 and 15, particularly in children with asthma. The association between the reduction in levels of NO_2 and $PM_{2.5}$ and the decrease in respiratory symptoms in children with asthma at both ages 10 and 15 was greater in boys and among children with family dog ownership.

CONCLUSIONS

The HEI Review Committee considered that Gilliland and colleagues conducted an important study to evaluate the outcomes of long-term regulatory actions. The study assessed how air pollution regulations introduced during the study period affected emissions and ambient levels of air pollutants in Southern California and whether changes in pollutant levels were, in turn, associated with improvements in children's respiratory health.

A major strength of the study was that it brought together extensive pollutant monitoring data and health effects information collected over 20 years in this unique and well-studied dataset from participants in the CHS. The investigators used data from a large number of children who lived in several communities in Southern California that differed in sources and levels of major pollutants (NO_2, PM, and O_3). They also collected detailed information about the children's health and relevant covariates in the cohort population.

The investigators found that emissions of pollutants and precursors decreased over the 20-year time frame of the study, as did most ambient pollutant levels, and particularly in communities with initially high levels of NO_2 and $PM_{2.5}$. Gilliland and colleagues noted that the large number of pollution control policy measures taken, with a focus on reducing motor vehicle and other emissions, made it difficult to link any specific action closely to a specific improvement in air quality. The Committee agreed that the regulations likely did contribute to those reductions, although it also noted the absence of analyses for other factors that might have contributed to changes in pollutant emissions.

The major health findings of the study were that decreases in long-term community-level averages of pollutants (particularly NO_2 and $PM_{2.5}$) across cohorts were associated with increased growth of children's lung function. In addition, in the cohort with the lowest overall levels of outdoor pollutants (Cohort E) there were fewer children with clinically relevant deficits in FEV_1 and FVC at age 15 than in the other two cohorts. Furthermore, decreases in levels of NO_2, $PM_{2.5}$, PM_{10}, and O_3 were also associated with decreases in the prevalence of bronchitic symptoms across the cohorts, particularly in children with asthma.

The Committee agreed with these health findings. However, it noted that the changes in lung function and respiratory symptoms were not uniform with regard to decreases in pollutant levels across the communities. There was, however, variability in the relationship between pollution decreases and changes in lung-function and respiratory symptom measures among the communities. This variability in lung-function and respiratory-symptoms results across communities suggested that unexplored between-community and within-community factors could be important. In addition, for all analyses, the reliance on multiyear averages from a single central monitor in each community likely reduced the ability to understand how exposure varied within a community and how to assess the impact of regulations and emissions reductions.

In summary, the Committee concurred with the investigators that decreases in levels of major outdoor pollutants were associated with improvements in children's health. However, the Committee noted that the analyses did not fully consider some differences between successive cohorts over time that might also have contributed to improvements in children's health making it more challenging to draw strong conclusions from the study unless alternative explanations for the health benefits can be ruled out.

Taken together, the findings of this important contribution to the accountability literature indicate that regulations directed toward reductions in emissions of mobile-source and other pollutants over the course of the study by national and California agencies were likely contributors to improvements in air quality that were linked to improvements in children's health, although the regulations themselves could not be definitively linked to the health improvements. Even so, the findings suggest the potential for important public health benefits resulting from levels of major outdoor pollutants that have been decreasing as a result of public policy measures.

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