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# Do Socio-Demographic Characteristics Modify the Association Between Air Pollution and Mortality & Morbidity?

Sabit Cakmak[1], Sara L. Martin[4], Claudia Blanco Vidal[2], Timur Gultekin[3], Vladislav Brion[4] and Maria Angelica Rubio[5]

[1]*Health Canada, Ottawa, Department of Statistics,*
[2]*Area Descontaminacion Atmosferica, Comisión Nacional del Medio Ambiente (CONAMA),*
[3]*Department of Anthropology, Ankara University,*
[4]*Health Canada, Ottawa, Department of Statistics*
[5]*Departamento de Ciencias del Ambiente, Facultad de Química y Biología, Universidad de Santiago de Chile*
*Centro de Desarrollo para la Nanociencia y Nanotecnología (CEDENNA),*
[1,4]*Canada*
[2,5]*Chile*
[3]*Turkey*

## 1. Introduction

Historical extreme air pollution events such as those experienced in London in the 1950s and 60s clearly demonstrated the potential of ambient air pollution to cause exacerbation of cardio-respiratory disease, manifested as pre-mature mortality and admission to hospital. In the intervening years, considerable efforts have been made to reduce pollution from the combustion of fossil fuels and industrial activity. Although these pollution mitigation strategies have been largely viewed as successful, evidence from population health studies in North America, Europe, South America, Mexico, Asia, Australia and New Zealand continues to identify ambient air quality as a population health concern (Table 1).

| Reference | Data | Location | Focus | Outcomes | Subpop. |
|---|---|---|---|---|---|
| Alberdi et al., 1998 | 1986-1992 | Madrid, Spain | TSP, $SO_2$ | NA, R, CV | Sex, Age >65 |
| Alberdi et al., 1998b | 1986-1992 | Madrid, Spain | TSP, $SO_2$ | NA, R, CV | Sex, Age >65 |
| Anderson et al., 1996 | 1987-1992 | London, England | BS, $SO_2$, $NO_2$, $O_3$ | NA, R, CV | |
| Bachárová et al., 1996 | 1987-1991 | Slovak Republic | TSP, $SO_2$ | A, NA, R, CV | |
| Ballester et al., 1996 | 1991-1993 | Valencia, Spain | TSP, $SO_2$ | NA, R, CV | Age >70 |

| | | | | | |
|---|---|---|---|---|---|
| Borja-Aburto et al., 1997 | 1990-1992 | Mexico City, Mexico | $O_3$, $SO_2$, TSP | A, NA, R, CV | Age |
| Borja-Aburto et al., 1998 | 1993-1995 | Mexico City, Mexico | $PM_{2.5}$ | NA, R, CV | Age >65 |
| Boucher et al., 1996 | 1985-1993 | Salt Lake and Utah counties, U.S. | $PM_{10}$ | NA | |
| Burnett et al., 1998 | 1980-1994 | Toronto, Canada | CO, $NO_2$, $SO_2$, TSP, $PM_{2.5}$, $PM_{10}$ | NA, R, CV, O | Age |
| Burnett et al., 1998b | 1980-1991 | 11 Canadian Cities | CO, $NO_2$, $SO_2$, $O_3$ | NA | |
| Burnett et al., 2000 | 1986-1996 | 8 Canadian Cities | $PM_{2.5}$, $PM_{10}$, $PM_{10-2.5}$ | NA | |
| Castillejos et al., 2000 | 1992-1995 | Mexico City, Mexico | $PM_{2.5}$, $PM_{10}$ $PM_{10-2.5}$ | NA | |
| Chock et al., 2000 | 1989-1991 | Pittsburg, Pennsylvania, U.S. | $PM_{2.5}$, $PM_{10}$ | NA, R, CV | Age |
| Cifuenties et al, 2000 | 1988-1996 | Santiago, Chile | $PM_{2.5}$, $PM_{10}$, CO, $NO_2$, $SO_2$, $O_3$ | NA | |
| Dab et al., 1996 | 1987-1992 | Paris, France | BS, $SO_2$, $O_3$, $NO_2$, $PM_{13}$ | R morbidity and mortality | |
| Daniels et al., 2000 | 1987-1994 | 20 cities, U.S. | $PM_{10}$ | A, CV | |
| Díaz et al., 1999 | 1990-1996 | Madrid, Spain | TSP, $SO_2$, $NO_2$, $NO_x$, $O_3$ | R, CV, Emergency hospital admission (94-96) | |
| Dockery et al., 1992 | 1985-1986 | St. Louis, Illinois and Missouri; Roanne county, Tennessee | $PM_{2.5}$, $PM_{10}$, Aerosols | Mortality | |
| Fairley, 1990 | 1980-1986 | Santa Clara County, California | $PM_{10}$ | NA | |
| Fairley, 1999 | 1989-1996 | Santa Clara County, California | $PM_{2.5}$ | NA, R, CV | |
| Reference | Data | Location | Focus | Outcomes | Subpop. |
| Goldberg et al., 2000 | 1995-1999 | Montreal, Quebec | predicted $PM_{2.5}$ | NA, CV, C | Age |

| | | | | | |
|---|---|---|---|---|---|
| Gouveia& Fletcher, 2000 | 1991-1993 | São Paulo, Brazil | $PM_{2.5}$, $PM_{10}$, CO, $NO_2$, $SO_2$, $O_3$ | NA, R, CV | Socioeco. sex, age |
| Hales et al., 2000 | 1988-1993 | Christchurch, New Zealand | $PM_{10}$, $NO_x$, $SO_2$, $O_3$, CO | NA, R, CV | Age >65 |
| Gwynn et al., 2000 | 1988-1990 | Buffalo, New York, U.S. | $H^+$ and $SO_4^{2-}$ PM | R, CV and A mortality and morbidity | |
| Hatzakis et al., 1986 | 1975-1982 | Athens, Greece | BS, $SO_2$ | Mortality | |
| Hoek et al., 1997 | 1983-1991 | Rotterdam, Netherlands | TSP, BS, $SO_2$, $O_3$, CO | Mortality | |
| Hoek et al., 2000 | 1986-1994 | The Netherlands | $PM_{10}$, BS | NA, R, CV | |
| Hong et al., 1999 | 1995-1996 | Inchon, South Korea | $PM_{10}$, $SO_2$,CO, $O_3$ | NA, R, CV | |
| Ito et al., 1993 | 1965-1972 | London, England | BS, $S0_2$, Acidic Aerosols | Mortality | |
| Ito et al., 1995 | 1985-1990 | Cook County, Illinois and Los Angeles County, California, U.S. | $PM_{10}$ | Mortality | |
| Ito et al., 1996 | 1985-1990 | Cook County, Illinois, U.S. | $PM_{10}$ | R, CV, C | Age, Sex, Race |
| Kelsall et al., 1997 | 1974-1988 | Philadelphia, Pennsylvania, U.S. | TSP | NA, R, CV | Age |
| Kinney & Özkaynak, 1991 | 1970 - 1979 | Los Angeles, County, California, U.S. | $O_x$, $SO_4$, $NO_2$, CO | NA, R, CV | |
| Kinney et al., 1995 | 1985-1990 | Los Angeles, County, California, U.S. | $PM_{10}$ | NA | |
| Klemm & Mason, 2000 | 1998-1999 | Atlanta, Georgia, U.S. | $PM_{2.5}$ | NA | Age (>65) |
| Kotesovec et al., 2000 | 1982-1994 | Northern Bohemia, Czech Republic | TSP, $SO_2$ | A, CV and C | Sex, Age |
| Krzyzanowski & Wojtyniak 1991/92 | 1977-1989 | Cracow, Poland | $SO_2$, $PM_{20}$ | NA, R, CV | Sex, Age |
| Le Tertre et al., 1998 | 1987-1990 | Paris, France | $S0_2$ | Mortality | |

| | | | | | |
|---|---|---|---|---|---|
| Lee et al., 1999 | 1991-1995 | Seoul and Ulsan, South Korea | TSP, $SO_2$, $O_3$ | NA | |
| Lee et al., 2000 | 1991-1997 | 7 South Korean cities | TSP, $SO_2$, $O_3$ | NA | |
| Reference | Data | Location | Focus | Outcomes | Subpop. |
| Lipfert et al., 2000 | 1992-1995 | Philadelphia, Pennsylvania | TSP | Mortality | |
| Lippmann et al., 2000 | Various | Detroit, Michigan, U.S. | $H^+$ and $SO_4^{2-}$ PM | Mortality and elderly morbidity | Age |
| Lyon et al., 1995 | 1985-1992 | Utah County, U.S. | $PM_{10}$ | NA, R, CV, O | Age |
| Machenbach et al., 1993 | 1979-1987 | The Netherlands | $S0_2$ | Mortality | |
| Mar et al., 2000 | 1995-1997 | Phoenix, Arizona, U.S. | $PM_{2.5}$, $PM_{10}$, $PM_{10\text{-}2.5}$ | NA, R, CV | |
| Michelozzi et al., 1998 | 1992-1995 | Rome, Italy | $PM_{10}$, $SO_2$, $O_3$, $NO_2$, CO | Mortality | |
| Moolgavak, 2000 | 1987-1995 | 3 U.S. Counties | $PM_{10}$, CO, $O_3$ | NA, R, CV | |
| Moolgavakar et al., 1995 | 1974–1984 | Steubenville, Ohio, U.S. | TSP, $SO_2$ | NA | |
| Moolgavakar et al., 1995b | 1973-1988 | Philadelphia, Pennsylvania, U.S. | TSP, $SO_2$,$O_3$ | NA | |
| Morgan et al., 1998 | 1989-1993 | Sydney, Australia | PM, $NO_2$, $O_3$ | NA, R, CV | |
| Ostro, 1995 | 1980-1986 | California, U.S. | $PM_{2.5}$ | NA, R, CV | |
| Ostro et al., 1996 | 1989-1991 | Santiago, Chile | $PM_{10}$ | NA, R, CV | Age >65 |
| Ostro et al., 1999 | 1989-1992 | Coachella Valley, California, U.S. | $PM_{10}$ | NA, R, CV | |
| Ostro et al., 1999b | 1992-1995 | Bangkok, Thailand | $PM_{10}$ | R, CV | Age |
| Ostro et al., 2000 | 1989-1998 | Coachella Valley, California, U.S. | $PM_{10}$ | NA, R, CV | |
| Peters et al., 2000 | 1982-1991 | Coal districts, Czech Republic;Bavarian districts, Germany | TSP, $SO_2$, $PM_{2.5}$, $PM_{10}$ | NA, R(Czech Republic only), CV | |
| Pope et al., 1992 | 1985-1989 | Utah County | $PM_{10}$ | NA, R, CV, O | |
| Pope et al., 1996 | 1985-1989 | Utah County | $PM_{10}$ | NA, R, CV, O | |

| | | | | | |
|---|---|---|---|---|---|
| Pope et al., 1999 | 1985-1995 | Wasatch Front, Utah | $PM_{10}$ | NA, R, CV, O | |
| Rahlenbeck & Kahl, 1996 | 1981-1989 | East Berlin, Germany | TSP, $SO_2$ | NA | |
| Rossi et al., 1999 | 1980-1989 | Milan, Italy | TSP, $SO_2$, $NO_2$, $PM_{13}$ | NA, R, CV | |
| Saldiva et al., 1995 | 1990-1991 | São Paulo, Brazil | $PM_{10}$ | NA | |
| Samet et al., 1998 | 1973-1980 | Philadelphia, Pennsylvania | TSP, $SO_2$ | NA | |
| Reference | Data | Location | Focus | Outcomes | Subpop. |
| Samet et al., 2000 | 1987-1994 | 20 cities, U.S. | $PM_{10}$ | NA, R, CV | |
| Schwartz & Dockery, 1992 | 1974–1984 | Steubenville, Ohio | TSP, $SO_2$ | NA | |
| Schwartz & Dockery, 1996 | 1973-1980 | Philadelphia, Pennsylvania | TSP, $SO_2$ | NA, R, CV | Age |
| Schwartz et al., 1990 | 1958-1972 | London, England | BS, $SO_2$ | Non-traumatic | |
| Schwartz, 1991 | 1973-1982 | Detroit, Michigan, U.S. | TSP | NA | |
| Schwartz, 1993 | 1985-1988 | Birmingham, Alabama, U.S. | $PM_{10}$ | NA | |
| Schwartz, 1994 | 1977 - 1982 | Cincinnati, Ohio, U.S. | TSP | A, R, CV | Age >65 |
| Schwartz, 2000 | 1986-1993 | 10 cities, U.S. | $PM_{10}$ | Mortality | Socioeco. |
| Schwartz, 2000b | 1986-1993 | 10 cities, U.S. | $PM_{10}$ | Mortality | Age >65 |
| Schwartz, 2000c | 1979-1986 | Boston, Massachusetts, U.S. | $PM_{2.5}$ | A, R, CV | |
| Schwartz, 2000d | 1974-1988 | Philadelphia, Pennsylvania | TSP and SO2 | NA | |
| Simpson et al., 1997 | 1987-1993 | Brisbane, Australia | $PM_{10}$, $SO_2$, $O_3$ | NA, R, CV | Age >65 |
| Simpson et al., 2000 | 1991-1996 | Melbourne, Australia | $PM_{2.5}$, $PM_{10}$ | NA, R, CV | Age |
| Smith et al., 1999 | Various | Alabama & Illinois, U.S. | $PM_{10}$ | Mortality | Age >65 |
| Spix & Wichmann, 1996 | 1976-1985 | Köln, Germany | TSP, $SO_2$, $NO_2$ | Mortality | |
| Spix et al., 1993 | 1980-1989 | Erfurt, Germany | TSP, $SO_2$ | Mortality | |

| | | | | | |
|---|---|---|---|---|---|
| Styer et al., 1995 | 1985-1990 | Utah, U.S. | $PM_{10}$ | NA | Age, Sex, Race |
| Sunyer et al., 1996 | 1985-1991 | Barcelona, Spain | BS, $NO_2$, $SO_2$, $O_3$ | NA, R, CV | Age >70 |
| Szafraniec et al., 1997 | 1993-1996 | Kraków, Poland | $SO_2$, $PM_{10}$ | NA, CV | Sex |
| Tobias & Campbell, 1999 | 1991-1995 | Barcelona, Spain | BS | Mortality | |
| Touloumi et al., 1994 | 1984-1988 | Athens, Greece | BS, CO, $SO_2$ | Mortality | |
| Touloumi et al., 1996 | 1987-1991 | Athens, Greece | BS, CO, $SO_2$ | Mortality | |
| Touloumi et al., 1997 | Various | 6 European Cities | $NO_2$, $O_3$ | Mortality | |
| Vigotti et al., 1996 | 1980-1989 | Milan, Italy | TSP, $SO_2$ | Respiratory morbidity | |
| Reference | Data | Location | Focus | Outcomes | Subpop. |
| Wichmann et al., 2000 | 1991-2002 | Erfurt, Germany | CO, $NO_2$, $SO_2$, $O_3$, $PM_{10}$ | Mortality | |
| Wietlishbach et al., 1996 | 1984-1989 | Zurich, Basle and Geneva, Switerland | TSP, CO, $NO_2$, $SO_2$, $O_3$ | NA, R, CV | Age >65 |
| Wojtyniak & Piekarski, 1996 | Various | Cracow, Lodz, Poznan and Wroclaw, Poland | $SO_2$, BS | NA, R, CV, D | |
| Wordley et al., 1997 | 1992-1994 | Brimingham, U.K. | $PM_{10}$ | R,CV morbidity | |
| X. Xu et al., 1994 | 1989 | Dongchen and Xichen, Beijing, China | TSP, $SO_2$ | NA, R, CV, C | |
| Z. Y. Xu et al., 2000 | 1992 | Shenyang, China | TSP, $SO_2$ | NA, R, CV, C, O | |
| Zanobetti & Schwartz, 2000 | 1986-1993 | 4 U.S. cities | $PM_{10}$ | NA | Sex, Race, Edu. |
| Zmirou et al., 1996 | 1985-1990 | Lyon, France | $S0_2$, $NO_2$, $O_3$, $PM_{13}$ | NA, R, CV, D | |

Table 1. Selected references examining air quality and health outcomes around the world with information on the years in which data was collected, as well as the location, the compounds, the health outcomes and subpopulations studied. In the compound column BS indicates black smoke and TSP indicates total suspended particulates. Cause of death categories studied in each paper were coded as A (accidental), NA (Non-accidental), R (respiratory including lung and chronic obstructive pulmonary disease), CV (cardiovascular or circulatory diseases), C (cancer), D (digestive system) and O (other).

Previous work that has found increases in morbidity and mortality are associated with both ambient air pollution and low socio-economic status (Dockery & Pop, 2002; Brunekreef & Holgate, 2002; Bascom et al., 1996; Hahn et al., 1996; Carr et al., 1992, Chen et al., 2001).
However, the literature regarding the effect of age, gender, and social status is conflicting with some studies documenting increased susceptibility studies (Cifuentes et al., 1999; Wojtyniak & Wysocki, 1989; Health Effects Institute[HEI], 2000; Pope, 2000 ) and others finding little or no effect (Gouveia & Fletcher, 2000; Samet et al., 2000; Zanobetti et al., 2000). A variety of factors have been implicated in the increased susceptibility to air pollution among the socially disadvantaged including, higher pollutant levels in living or working areas, increased cigarette smoking, fewer dietary fruits and vegetables, and reduced access to medical care (O'Neill et al., 2003, Sexton et al. 1993). However, identification of subgroups which are more susceptible to the effects of air pollution is important for three reasons: 1) developing targeted intervention programs; 2) determining whether the air pollution-health effects found in one region can be extrapolated to other geographic regions; 3) setting effective air pollution policies that reduce risk for the entire population. This study investigates whether age, gender and an indicator of social status – educational attainment – modify the effect of particulate air pollution on mortality.

## 2. Methods

### 2.1 Air pollution data

Daily air pollution data for the nine communities (communas) that make up the Conception Region (Fig. 1.), Tomé, Penco, Talcahuano, Hualpén, Concepción, San Pedro de la Paz, Chiguayante, Lota, and Coronel, were obtained from monitoring stations located within each of the centers (Fig. 2.). We obtained information for the period from 1 January 2000 to 31 December 2009, although some stations had information for only a subset of these dates. The information collected was the average concentration of particulate matter with mass median aerodynamic diameter less than 10 microns ($PM_{10}$) over 24 hour periods

### 2.2 Mortality and sociodemographic data

The daily number of non-accidental deaths (ICD-9 <800) in the study areas were obtained from the Instituto Nacional de Estadisticas, the official source of statistical data in Chile from 1 January 2000 to 31 December 2009 for all nine areas. The daily number of hospitalizations were obtained for five of the areas under study: Tomé, Talcahuano, Concepción, , Lota, and Coronel for the period of January 1 2006 to December 31 2007. Age, gender, and individual educational attainment data were obtained from the Departamento de Estadísticas e Información en Salud (DEIS).

### 2.3 Statistical medhods

We used time series analyses and assumed both a Poisson distribution and that there was a linear association between ambient air pollution and mortality or morbidity on a logarithmic scale (Rupprecht et al., 1995).
Natural splines were created for air pollution concentrations on the day of study with one knot for each of 15, 30, 60, 90, 120, 180, and 365 days of observation. We then selected the model with the number of knots that either minimized the Akaike Information Criteria

Fig. 1. Map of Chile. The red area on the map has been declared a non-attainment zone because of failure to maintain daily $PM_{10}$ concentrations below a standard threshold. The area includes nine communities with a population of 1 million inhabitants.

(AIC), a measure of model prediction, or maximized the evidence that the model residuals did not display any type of structure, including serial correlation, using Bartlett's test (Lindstrom & Bates, 1990; Priestly, 1981). We plotted model residuals against time and found neither a pattern nor a significant correlation between air pollution and time. Once we had selected the optimal model for time, we assessed the value of including terms for the twenty-four hour means of temperature, humidity, and barometric pressure. The best meteorological predictors of death were temperature and humidity while humidex (Meterorological Service of Canada, 2000), a composite measure of temperature and humidity, was the best meteorological predictor of morbidity. We considered temperature and humidex readings on the day of death and the day prior to death and accounted for non-linear associations with death by using natural spline functions. Indicator functions for the day-of-the-week were also included. The association between air pollutants and death was tested at lags of zero to seven days and results were presented for the lags which maximized the effect size. Results from each urban center were pooled using a random effects model.


Fig. 2. Detailed Map of Chile. The locations of ten metropolitan areas highlighted in circles

Here we present the increase in relative risk (RR) of mortality or morbidity with 95% confidence intervals for an increase in $PM_{10}$ concentration equal to the interquartile range of the pollutant's concentration over the period of study. The interquartile range includes the middle fifty-percent of the exposure data and provides a realistic estimate of the day-to-day changes in the pollutant's concentration. The interquartile range is a nonparametric measure of the data's spread and, as such, is not influenced by skewed data, extreme values or outliers which are unstable and infrequently seen. A random effects model was used to pool the estimates of relative risk following a DerSimonian- Laird test for homogeneity among estimates.

## 3. Results

Regional population sizes varied by over fourfold from 49,923 in Penco to 224,212 in Conception (Table 2). The number of daily deaths varied by four to fivefold between

Conception and Penco. In the population of about one million people, there was an average of 15 deaths per day. The twenty-four hour mean concentrations of particulate matter varied by about 50% - 60% between regions with Chiguayante and San Pedro de la Paz reaching the greatest concentrations of $PM_{10}$ (Table 2).
Risk of mortality from cardiac disease appeared to be particularly sensitive to increases in air pollution with an estimated increase of 26% (7% to 49%). The point estimate for mortality relative risk was somewhat greater in the oldest compared to the youngest age group, however, the effect was not significantly greater for those at least eighty-five years old compared to less than sixty-five ($p > 0.05$). The point estimates for mortality risk from $PM_{10}$ were similar for males and females ($p > 0.05$) indicating a lack of effect modification by sex. The effect of $PM_{10}$ on mortality was greatest among those with the lower level of educational attainment. An interquartile increase in pollutants among those who did not complete a college or university degree was associated with a 16.8% (3% to 33%) increase in mortality whereas among college and university graduates there was 13% (-1% to 28%) increase, which was not statistically significant. The risk of death associated with air pollution was particularly high among the elderly with low educational attainment with an increase of 19% (3% to 35%).

| | Population 100,000s | Total Mortality | Cardiac Mortality | Respiratory Mortality | $PM_{10}$ ($\mu g/m^3$) | Total Hospitalization | Temperature |
|---|---|---|---|---|---|---|---|
| **Tomé** | 5.47 | 0.935 (0.964) | 0.081 (0.288) | 0.285 (0.539) | 47.613 (45.975) | 12.441 | 12.592 (4.388) |
| **Penco** | 4.99 | 0.681 (0.819) | 0.067 (0.262) | 0.175 (0.423) | 56.118 (49.525) | NA | 12.592 (4.388) |
| **Talcahuano** | 17.13 | 3.010 (1.832) | 0.264 (0.526) | 0.791 (0.921) | 50.030 (28.060) | 61.760 | 13.355 (5.871) |
| **Hualpén** | 8.8 | 1.272 (1.131) | 0.113 (0.343) | 0.346 (0.578) | 34.645 (19.025) | NA | 13.355 (5.871) |
| **Concepción** | 22.42 | 3.487 (1.939) | 0.321 (0.570) | 1.006 (1.002) | 41.734 (23.350) | 101.414 | 13.355 (5.871) |
| **San Pedro** | 8.92 | 0.975 (1.006) | 0.070 (0.265) | 0.269 (0.524) | 56.118 (49.525) | NA | 13.355 (5.871) |
| **Chiguayante** | 9.98 | 1.042 (1.022) | 0.091 (0.298) | 0.302 (0.544) | 56.118 (49.525) | NA | 12.852 (3.101) |
| **Lota** | 4.89 | 1.126 (1.077) | 0.100 (0.320) | 0.293 (0.544) | 49.778 (31.325) | 15.047 | 12.852 (3.101) |
| **Coronel** | 10.31 | 1.344 (1.173) | 0.129 (0.365) | 0.358 (0.610) | 52.148 (29.500) | 22.280 | 12.852 (3.101) |

Table 2. Population size, mean daily total mortality, 24-hour mean daily air pollution levels and 24-hour mean weather for nine urban centers in Chile from January 2000 to December 2009. Mean daily total mortality rates and 24 hour mean weather variables are accompanied by their standard deviation, while the interquartile range is reported for the concentration of $PM_{10}$.

When regions were pooled, an interquartile increase in concentration of $PM_{10}$ was associated with a 5.5% (0.3% to 11%) increased risk of death from all causes (Table 3).

| | | Relative Risk |
|---|---|---|
| Mortality | All Causes | 1.055 (1.003, 1.109) |
| | Cardiac | 1.260 (1.065, 1.490) |
| | Respiratory | 1.041 (1.024, 1.076) |
| Sex | Male | 1.043 (1.020, 1.085) |
| | Female | 1.061 (1.024, 1.099) |
| Age | < 64 | 1.053 (1.013, 1.096) |
| | 65 - 74 | 1.048 (1.007, 1.089) |
| | 85 + | 1.061 (1.016, 1.107) |
| Education | < College | 1.168 (1.029, 1.325) |
| | > College | 1.130 (0.998, 1.280) |
| Ages > 85 & lowest educational strata | | 1.190 (1.031, 1.349) |

Table 3. Increase in relative risk of mortality by age group, sex, educational attainment, associated with an interquartile increase in $PM_{10}$ adjusted for long-term trends, day-of-the-week, and temperature and humidity for nine urban centers in Chile from January 2000 to December 2009.

The risk of hospitalization from all causes and from respiratory disease showed no evidence of effect modification by age or sex with an increase in air pollution (Table 4). However, risk of hospitalization from cardiac disease was greatest among those 85 years old and greater, with an increase of 23% (6% to 44%) among the elderly versus 3% (-3% to 10%) among those less than 64 years of age; but, similar to risk of hospitalization from all cause and respiratory disease, cardiac disease showed no effect modification by sex.

| | | All Cause RR | Cardiac RR | Respiratory RR |
|---|---|---|---|---|
| **Age** | **All** | 1.032 (1.011 to 1.053) | 1.029 (0.983 to 1.077) | 1.056 (1.005 to 1.111) |
| | **< 64** | 1.037 (1.017 to 1.059) | 1.033 (0.974 to 1.097) | 1.067 (1.014 to 1.123) |
| | **65 to 74** | 1.034 (0.996 to 1.074) | 1.089 (1.006 to 1.178) | 1.071 (0.945 to 1.214) |
| | **75 to 84** | 1.036 (0.991 to 1.084) | 1.050 (0.969 to 1.137) | 1.119 (1.003 to 1.249) |
| | **> 85** | 1.048 (0.977 to 1.124) | 1.232 (1.058 to 1.435) | 1.081 (0.946 to 1.235) |
| **Sex** | **All** | 1.032 (1.011 to 1.053) | 1.029 (0.983 to 1.077) | 1.056 (1.005 to 1.111) |
| | **Females** | 1.031(1.010 to 1.054) | 0.998 (0.940 to 1.059) | 1.046 (0.986 to 1.109) |
| | **Males** | 1.034 (1.007 to 1.062) | 1.055 (0.998 to 1.116) | 1.073 (1.006 to 1.144) |

Table 4. Relative Risk (RR) of hospitalization (morbidity) associated with an interquartile increase in concentrations of $PM_{10}$ adjusted for long-term trends, day-of-the-week, and humidex for the five urban centers in Conception from January 1 2006 to December 31 2007.

## 4. Discussion

Although progress has been made steadily over time at reducing ambient concentrations of particulate matter ($PM_{10}$) (Fig.3), the results of this work suggests that there remains a risk to human health from exposure to this pollutant.The burden of mortality and morbidity due to increases particulate matter ($PM_{10}$) in the short-terms has the greatest influence on the health of those who are elderly with low educational attainment and those with cardiac disease. In general, effect modification was observed by age and by education but not by sex and effect modification was less pronounced for morbidity data than for mortality data. Air quality guidelines that seek to protect the entire population, including high risk subgroups, should consider the greater sensitivity of those who are elderly, have lower educational attainment or suffer from cardiac disease.

### 4.1 Effect modification by age and educational attainment

Age significantly modified the effect of cardiac morbidity for the five Chilean communities studied here. Modification by age was less pronounced for all cause mortality, all cause morbidity and respiratory morbidity. Similarly, we observed little modification by educational attainment for total mortality. However, we did find that the combination of old age and low educational attainment resulted in elevated risk from air borne particulate matter.

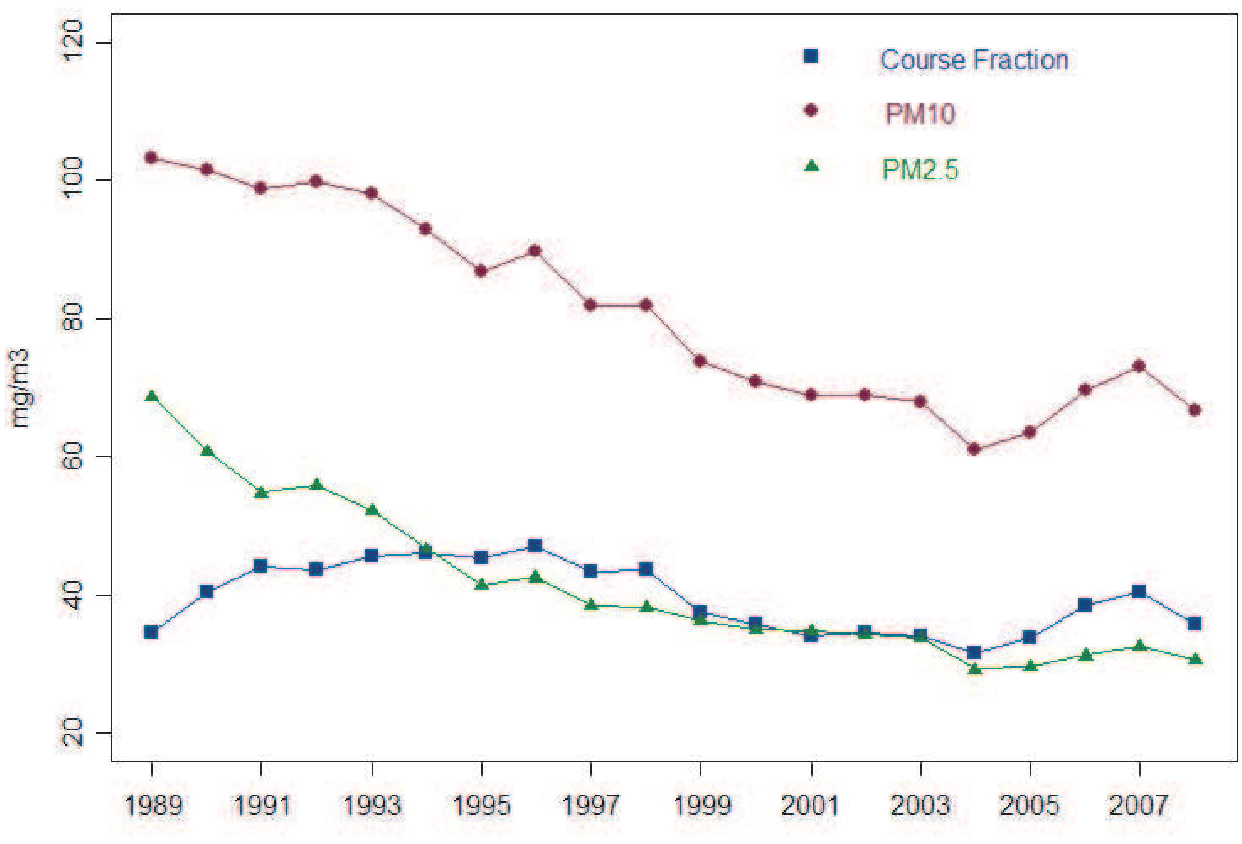


Fig. 3. Air pollution levels over time for all nine centres combined.

Previous work has reported modification of the effect of air pollutants by age (Bell et al., 2005; Pope, 2000; Pope et al., 2002; Spix et al., 1998; Zanobetti et al., 2000). For example, previous work indicated that compared to those under sixty-five years of age, Chileans eighty five years and older were observed to be more than twice as likely to die from acute increases in $PM_{10}$, and over 50% more likely to die from increases in ozone and $SO_2$ (Camak et al., 2009). Similarly, Bell et al. (2008) reported increased mortality effects in the elderly from ozone in The National Morbidity Mortality and Air Pollution Study of 98 U.S cities (Bell & Dominici, 2008) and Filleul et al. (2004) reported a greater effect of air pollution mortality in those over sixty-five years old in France, though these effects were not statistical significant (Filleul et al., 2004).

Previous work has also reported effect modification by educational attainment and other indicators of social status (Bell et al., 2008; Forastiere et al., 2009; Dales, 2002; O'Neil et al., 2008; Ou et al., 2008; Prescott & Vestbo, 1999; Zanobetti et al., 2000). For example, in the Harvard Six-Cities and American Cancer Society cohort studies, there was an increased risk of mortality from long-term exposure to particulate matter among those with lower educational attainment (Health Effects Institute, 2000; Pope et al., 2002; Villeneuve et al., 2002). Similarly, in Hamilton, Canada, the non-accidental mortality risk estimates associated with sulphur dioxide and coefficient of haze were greater in areas of the city with lower educational attainment as well as greater employment in manufacturing (Jerrett et al. 2004). However, this finding is far from consistent: no relation to level of education was found in a study of mortality risk estimates from gaseous and particulate air pollution in Hong Kong (Ou et al., 2008); no effect modification by education was found among urban Americans from 98 communities for ozone levels (Bell & Dominici, 2008); and neither a time-series study of 20 U.S (Samet et al., 2000) cities nor one focusing on Vancouver, Canada found social status modified the effect of air pollution on mortality (Villeneuve et al., 2003). Furthermore, a study of São Paulo, Brazil the authors reported that a monotonically increasing effects of air pollution with increasing education (Gouvenia & Fletcher, 2000). This type of conflicting results lead the authors of a systematic review of the Medline database up to May 2006 to state that because of inconsistent findings in both long-term and short-term exposure studies "Current evidence does not yet justify a definitive conclusion that socioeconomic characteristics modify the effects of air pollution on mortality" (Laurent et al., 2009). Nevertheless, here we report that in combination with old age, risk increases with lower educational attainment.

### 4.2 The influence of social status

There are many possible reasons why one might expect lower socioeconomic position to increase susceptibility to the deleterious effects of air pollution including: increased exposure to the air pollutants of interest, increased exposure to co-pollutants from occupational dusts and fumes and cigarette smoke, fewer dietary fruits and vegetables, and reduced access to medical care and medicines (O'Neill et al., 2003; Sexton et al., 1993; Spix et al., 1998). Unfortunately, information on these variables was not available. However, because the overall effect size is based on the association between daily changes in air pollution and daily changes in mortality or morbidity, these other variables would only confound the overall pollution-illness association if they change day-to-day which is unlikely (Bell et al., 2005). It is possible that these variables differ between the educational groups and may partly account for the between-group estimates of effect found here.

## 5. Conclusion

We found that the burden of all cause mortality and cardiac morbidity due to increased particulate air pollution is disproportionately experienced by the elderly who have low educational attainment. These findings suggest that the determination of air quality guidelines designed to protect the general population may be insufficient to protect this vulnerable subgroup.

## 6. Acknowledgments

The authors would like to thank Dra. Danuta Rajs Grzebien of the Departamento de Estadísticas e Información de Salud, Ministerio de Salud for providing morbidity data, and Roberto Martínez González and Joyce Vera Bascour from the Secretaría Regional Ministerial del Medio Ambiente Region Metropolitana for providing data and comments.

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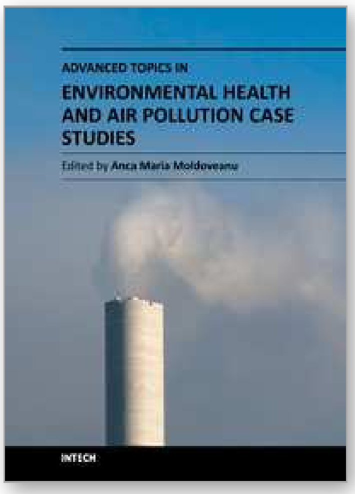


**Advanced Topics in Environmental Health and Air Pollution Case Studies**
Edited by Prof. Anca Moldoveanu

ISBN 978-953-307-525-9
Hard cover, 470 pages
**Publisher** InTech
**Published online** 29, August, 2011
**Published in print edition** August, 2011