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Lung function association with outdoor temperature and relative humidity and its interaction with air pollution in the elderly

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ABSTRACT

While the effects of weather variability on cardio-respiratory mortality are well described, research examining the effects on morbidity, especially for vulnerable populations, is warranted. We investigated the associations between lung function and outdoor temperature (T in Celsius degrees (°C)) and relative humidity (RH), in a cohort of elderly men, the Normative Aging Study.

Our study included 1103 participants whose forced vital capacity (FVC), forced expiratory volume in one second (FEV_1), and weather exposures were assessed one to five times during the period 1995–2011 (i.e. 3162 observations). Temperature and relative humidity were measured at one location 4 h to 7 days before lung function tests. We used linear mixed-effects models to examine the associations with outdoor T and RH.

A 5-degree increase in the 3-day moving average T was associated with a significant 0.7% decrease (95%CI: −1.24, −0.20) in FVC and a 5% increase in the 7-day moving average RH was associated with a significant 0.2% decrease (95%CI: −0.40, −0.02) in FVC and FEV_1. The associations with T were greater when combined with higher exposures of black carbon with a 1.6% decrease (95%CI −2.2; −0.9) in FVC and a 1% decrease (95%CI −1.7; −0.4) in FEV_1. The relationships between T and RH and lung function were linear. No synergistic effect of T and RH was found.

Heat and lung function are two predictors of mortality. Our findings suggest that increases in temperature and relative humidity are related to decreases in lung function, and such observations might be amplified by high black carbon levels.

1. Introduction

Extreme weather conditions (hot and cold) as well as variations across the common range of temperatures have been associated with increased morbidity and mortality (Basu and Samet, 2002; McGeehin and Mirabelli, 2001; Ye et al., 2012). Interestingly, a recent multi-country study, reported that most of the effects of temperature on mortality was due to moderately non-optimum temperatures rather than extreme heat or cold events (Gasparrini et al., 2015). Such issues have received more attention in the light of climate change (i.e. long-term trends in climate) and its expected global warming effect, which will likely increase the occurrence of diseases especially in populations with limited adaptive capacities.

Of importance, much of the excess weather-related mortality is from pulmonary and cardiovascular diseases (Basu and Samet, 2002). However, most of the research on pulmonary effects of weather variations (i.e. short-term variations) remains limited to time series studies on respiratory hospital admissions (Ye et al., 2012). Such studies have reported associations for respiratory diseases admissions and increase in ambient temperature, particularly in the elderly (Michelozzi et al., 2009), who are less able to cope with environmental stressors due to age-related decline in physiological capacity and co-morbidities. The elderly population (> 65 years old) is expected to rise up to 19% of the US population by 2030 (http://www.aoa.gov/aoaroot/aging_statistics/

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index.aspx), which will likely increase impact of climate changes on public health. While research examining the associations of weather and morbidity in vulnerable populations is warranted (Basu and Samet, 2002; McGeehin and Mirabelli, 2001), to our knowledge, no such study has been conducted yet on lung function in the elderly.

We investigated the short-term associations between lung function and ambient temperature and relative humidity, in a cohort of elderly men, the Normative Aging Study (NAS). We adjusted our results for potential confounding by air pollution and investigated effect modification by particulate air pollution and ozone. We further examined susceptibility factors such as respiratory diseases and diabetes.

2. Methods

2.1. Study population and lung function assessment

The Normative Aging Study is a longitudinal closed cohort established by the U.S. Veterans Administration in 1963 (Bell et al., 1966). It enrolled 2280 male volunteers living in the Boston area, aged between 21 and 80 years at entry, who underwent an initial health screening that determined they were then free of known chronic medical conditions. Participants returned every 3–5 years for clinical examinations, which took place in the morning after an overnight fast and smoking abstinence. During these visits, height, weight, and medication use were assessed. Pulmonary disorders confirmed by a physician (asthma, chronic bronchitis, emphysema) and smoking history were collected using the American Thoracic Society (ATS) questionnaire (Ferris, 1978). Spirometric tests were performed following the ATS guidelines, as previously reported (Sparrow et al., 1987). Spirometry was assessed in the standing position with a noseclip using a 10-litre water-filled survey-recording spirometer and an Eagle II minicomputer (Warren E. Collins, Braintree, Massachusetts). Values were adjusted by body temperature and pressure. A minimum of three acceptable spirograms was obtained, of which at least two were reproducible within 5% for both forced vital capacity (FVC) and forced expiratory volume in one second (FEV_1); the highest of the reproducible trials was selected from a given encounter. Each technician underwent training prior to taking measurements for this study. Chronic obstructive pulmonary disease (COPD) was defined as meeting the Global Initiative for Chronic Obstructive Lung Diseases (GOLD) stage II (or higher) criteria (FEV1/FVC < 70% and FEV1 < 80% predicted, using the Crapo et al. equations (Crapo et al., 1981)) at least twice consecutively for participants with two or more visits and once for participants having only one visit. Methacholine challenge tests were conducted between 1984 and 2000 using procedures adapted from Chatham and colleagues (Chatham et al., 1982). We used data from the most recent test available for each subject. Participants having ischemic heart disease or baseline FEV_1 at < 60% of the predicted value were excluded from the test, and some subjects elected not to participate. Methacholine inhalations were administered at incremental doses corresponding to 0, 0.330, 1.98, 8.58, 16.8, and 49.8 μmol (Izbicki and Bar-Yishay, 2001; Jayet et al., 2005). Participants whose FEV_1 declined by 20% in response to any of the doses at or before 8.58 μmol were classified as having airway hyperresponsiveness. Participants whose FEV_1 did not decline by 20% in response to any of the administered doses and those who demonstrated a 20% decline in FEV_1 only from a higher methacholine dosage (16.8 or 49.8 μmol) were categorized as having no airway hyperresponsiveness. Our study included 1103 participants whose lung function, temperature and relative humidity were assessed one to five times between 1995 and 2011 (i.e. 3162 observations). Participants provided written informed consent and the study was approved by the institutional review boards of all participating institutions.

2.2. Environmental data

We obtained hourly data of ambient temperature (°C) and relative humidity (%) collected at the Boston Logan airport. Exposure to particulate black carbon and ozone was estimated using fixed monitoring stations. Black carbon concentrations were measured using an aethalometer (Magee Scientific Inc., Berkeley, CA, USA) positioned at the top of a building located < 1 km from the medical examination center, where the participants' visits took place. Ozone was assessed by the average of the 4 local state monitors operated by the Massachusetts Department of Environmental Protection (Mass DEP). We considered a range of short-term exposure windows for temperature, humidity and air pollution indices preceding each subject's examination, including: 4 h, 24 h (ie. lag 0), previous day (lag 1), previous 2–6 days (lag 2-lag 6) and 2–7-day moving averages. Since all visits were scheduled during the morning, exposure windows were calculated from 8 a.m. the day of the visit (e.g.: 24 h average is the average from 8 a.m. the day of the visit to 8 a.m. the previous day).

2.3. Statistical analysis

We used the natural logarithms of FVC and FEV_1 to stabilize the variance and increase the normality of the residuals. Separate models were run for each lung function measurement. The 4-h time-window, 0–6 day distributed lag and moving averages were investigated in separate models. We applied a mixed linear model to examine the associations of ambient temperature and relative humidity with lung function:

$$Y_{i(t)} = \beta_0 + u_i + f_1(\beta_1 + Temperature_{i(t)}) + f_2(\beta_2 + Relative{\cdot}humidity_{i(t)}) + f_3(\beta_3 + confounders_{i(t)}) + \varepsilon_{i(t)} \quad (1)$$

with $\varepsilon \sim N(0,\sigma^2)$ and $u \sim N(0,\sigma_u^2)$ where: $Y_{i(t)}$ is the log-transformed lung function measurement for participant i at visit t, β_0 is the intercept, u_i is the random effect for participant i, f_1 and f_2 are the distributed-lag functions with sets of coefficients β_1 and β_2 constrained by a second degree polynomial structure that corresponds to the temperature and relative humidity associations with lung function at lags 0–6 days, β_3 is the vector of unknown parameters of confounders for participant i at visit t. Potential confounders were selected *a priori*, and we added a quadratic term whenever it was significant: age (linear and quadratic), height (linear and quadratic) and standardized weight (weight-average weight) (linear), race (white/black), education level (< 12, 12, 13–15, > 15 years), smoking status (former/current/never), cumulative smoking in pack-years, season of the medical exam (using sine and cosine of time), day of the week, doctor's diagnosis of chronic lung conditions (asthma, emphysema, chronic bronchitis) (yes/no), methacholine responsiveness (yes/no), medication use (sympathomimetic α and β, anticholinergics) (yes/no).

2.3.1. Primary analyses

We investigated simultaneously ambient temperature and relative humidity and examined separately the 4-h time-window and the polynomial distributed lag (PDL). We then investigated cumulative exposures (i.e. 2- to 7-day moving averages) and examined the shape of their relationship with lung function using penalized spline models in the generalized additive mixed models framework. The number of degrees of freedom for ambient temperature and relative humidity were chosen by cross-validation.

In our sensitivity analyses, since traffic-related air pollutants concentrations have been associated with lung function and are influenced by the prevailing meteorological conditions, we studied possible confounding by further adjusting for the 7-day moving averages of black carbon and ozone concentrations. We also adjusted for potential selection bias by applying inverse probability weighting (Hernán et al., 2006). We used logistic regression to calculate the probability of having