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Associations between short/medium-term variations in black smoke air pollution and mortality in the Glasgow conurbation, UK

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ABSTRACT

Objectives: To examine associations between short/medium-term variations in black smoke air pollution and mortality in the population of Glasgow and the adjacent towns of Renfrew and Paisley over a 25-year period at different time lags (0–30 days).

Methods: Generalised linear (Poisson) models were used to investigate the relationship between lagged black smoke concentrations and daily mortality, with allowance for confounding by cold temperature, between 1974 and 1998.

Results: When a range of lag periods were investigated significant associations were noted between temperature-adjusted black smoke exposure and all-cause mortality at lag periods of 13–18 and 19–24 days, and respiratory mortality at lag periods of 1–6, 7–12, and 13–18 days. Significant associations between cardiovascular mortality and temperature-adjusted black smoke were not observed. After adjusting for the effects of temperature a 10 μg m^{-3} increase in black smoke concentration on a given day was associated with a 0.9% [95% Confidence Interval (CI): 0.3–1.5%] increase in all cause mortality and a 3.1% [95% CI: 1.4–4.9%] increase in respiratory mortality over the ensuing 30-day period. In contrast for a 10 μg m^{-3} increase in black smoke concentration over 0–3 day lag period, the temperature adjusted exposure mortality associations were substantially lower (0.2% [95% CI: −0.0–0.4%] and 0.3% [95% CI: −0.2–0.8%] increases for all-cause and respiratory mortality respectively).

Conclusions: This study has provided evidence of association between black smoke exposure and mortality at longer lag periods than have been investigated in the majority of time series analyses.

1. Introduction

There is extensive literature that, by consistency, provides evidence of a causal link between daily variations in air pollution and human mortality rates (e.g. see reviews by Pope and Dockery, 2006 and Brunekreef and Holgate, 2002). Similarly, other studies have demonstrated that low air temperatures have a strong association with increased cardiorespiratory mortality (Braga et al., 2001; Pattenden et al., 2003). In earlier studies air temperature was considered a simple confounder in relation to short-term air-pollution effects (Lippmann and Ito, 1995). Thus adjustments were made by including recent air temperature in the epidemiological models used, typically examining the effects of temperature-adjusted air pollution on the same day as the health outcome and/or variations that were measured up to a few days previously. However, several studies have suggested that effects on mortality of both cold temperature (Carder et al., 2005; Keatinge and Donaldson, 2001) and air pollution (Carder et al., 2008; Dominici et al., 2003; Goodman et al., 2004; Schwartz, 2000; Zeger et al., 1999) persist for considerably longer time periods.

We have found some evidence of interaction between (cold) temperature and particulate matter air pollution in their effect on all-cause and respiratory mortality (Carder et al., 2008). This is biologically plausible since, for example, it is known that cold will adversely affect respiratory muco-ciliary function (Williams et al., 1996) and may thus impede the clearance of pollutants. Our earlier analyses of the short-term effects of air pollution have been restricted to periods post-dating 1981 (Carder et al., 2008; Prescott et al., 1998). The aim of the study described here was to determine the effects of short/medium-term variations in black smoke air pollution and air temperature on mortality in the population of Greater Glasgow and the neighbouring towns of Renfrew and Paisley over a 25-year period, for direct comparison with the effects of long-term exposure to black smoke (Beverland et al., 2012b) in a cohort sub-group resident in the same geographical area (Beverland et al., 2012a; Yap et

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al., 2012). Thus, Poisson regression models were used to investigate the relationship between lagged black smoke concentrations (using a wide range of lag periods) and daily mortality, with allowance for confounding by cold temperature, over the period January 1974 to December 1998.

2. Methods

2.1. Health data

The study area encompassed a population of approximately 1.5 million residents in the densely populated and industrialised contiguous urban area of Glasgow, Paisley, and Renfrew in central Scotland, United Kingdom (the Glasgow conurbation). To provide an indication of geographical scale the Glasgow conurbation can be encompassed within a radius of 12 km, with Renfrew and Paisley encompassed by radii of 1.5 and 3.5 km, respectively, within this 12-km radius. The Information and Statistics Division of the Common Services Agency of the National Health Service in Scotland supplied mortality data for the period January 1974 to December 1998 for residents, age 50 and over, of the Glasgow conurbation. Deaths from all non-accidental causes (referred to hereafter as all cause), cardiovascular causes (ICD-9 codes 410–414, 426–429, 434–440: essentially including cardiac and cerebral ischaemia but excluding cerebral haemorrhage), respiratory causes (ICD-9 codes 480–487 and 490–496: chronic obstructive pulmonary disease (COPD), asthma and pneumonia), lung cancer (ICD-9 code 162) and 'other' causes (all non-accidental causes minus codes specified above) were considered.

Lung cancer was included to match the outcomes examined in our related cohort study (Yap et al., 2012). While long-term exposure to air pollution might be causally linked to lung cancer after several years of exposure, the long latency of lung cancer implies that one might not expect deaths from lung cancer per se to be related to short-term changes in pollution on a scale of days or even months. However, our previous work discusses plausible explanations for the finding of a significant association between black smoke and mortality in groups containing subjects who did not have a specified cardiac or respiratory code recorded as the primary (underlying) cause of death (Carder et al., 2008). The "mode" or secondary cause of death in many diseases, regardless of the primary underlying pathology, is often respiratory and this is likely to be particularly true when the primary pathology is lung cancer (not only because of COPD and lung cancer being caused largely by smoking, but also because the presence of a bronchial tumour predisposes to distal pneumonia). It is therefore plausible that short-term exposure to air pollution contributes to this final "mode" of death.

2.2. Meteorological and air pollutant data

Hourly air temperature data for were obtained from the British Atmospheric Data Centre (BADC, 2002) for Glasgow Airport. These were used to calculate the daytime mean temperature (T) for each day, taken as the average of the 7 am to 11 pm hourly values. Our previous work (Carder et al., 2005) had observed a non-linear relationship between temperature and mortality: mortality increased as temperature decreased but with a steeper increase at lower temperatures. Carder et al. (2005) examined the shape of the relationship between mortality and daytime mean temperature at each lag period by fitting cubic spline models with 7 degrees of freedom. To allow for this in a manner that would allow simple interpretations of model coefficients, two separate linear relations were assumed over different parts of the temperature range constrained to join at a "knot". The position of the knot was decided by comparing the log likelihoods of models with different choices of knot as suggested by the initial plots and choosing the one that fitted the data best—that is, at 11 °C. The double linear model included two modified temperature variables referred to here as "high" and "low" defined as follows:

$$\text{High} = \text{T}-11 \text{ if } T \geq 11^{\circ}\text{C}, \text{ 0 otherwise}$$
$$\text{Low} = \text{T}-11 \text{ if } T < 11^{\circ}\text{C}, \text{ 0 otherwise}.$$

We had also observed the effect of temperature on mortality to persist for periods beyond two weeks (Carder et al., 2005). Therefore, these variables were computed for T lagged by 0 (same day), 1–6 days (i.e. average of temperatures on the previous 1–6 days), 7–12 days, 13–18 days, 19–24 days and 25–30 days. Days were grouped in this way to minimise the number of variables in the regression models and thus reduce the problem of multi-collinearity (Carder et al., 2005, 2008).

The prevailing year-round wet climate in the West of Scotland is such that low relative humidity is seldom obvious as an environmental stressor. Low temperatures and wind-chill are more obvious stressors that may be plausibly linked to mortality in susceptible people in this geographical area. However, our earlier work found little indication that "wind chill" temperature was a better predictor of mortality than "dry bulb" temperature (Carder et al., 2005) so we focused our analyses with adjustments for temperature only.

Our analyses were based on daily records of black smoke concentration at a single monitoring station in central Glasgow which had few missing values and was situated in a residential area with medium to high-density housing interspersed with some industrial undertakings (classification A2/B2 according to the UK National Air Quality Archive, DEFRA, 2005). From a review of approximately 10 potential monitoring sites in the conurbation, bearing in mind prevailing winds, population distribution and other factors, this was considered the most appropriate single site. Black smoke is a metric of the optical darkness of airborne particulate matter collected on filter media (Heal and Quincey, 2012; Quincey et al., 2009). Although quantified in units of $\mu g\ m^{-3}$ black smoke concentrations do not equate directly to the mass of a particular size fraction of airborne particulate matter. However, consistent standard calibrations (e.g. DETR, 1999) have been used for many decades to convert reflectance to nominal concentration such that black smoke data are important measures of historic air pollution. The DETR (1999) calibration procedures were used in the computation of UK government archived black smoke data used in the analyses in this paper. The use of black smoke as a metric of particulate matter air pollution is well-established in the epidemiological research community and has been shown to be a good marker for traffic and other primary combustion-related urban air pollution (Hochadel et al., 2006; Hoek et al., 2001) often at least as predictive of negative health outcomes as PM_{10} or $PM_{2.5}$ (Janssen et al., 2011).

2.3. Statistical analysis

All analyses were undertaken using Splus software (Version 2000), using generalised linear (Poisson) models (GLMs) with natural cubic splines to capture seasonal and other long-term effects. The convergence tolerances of the GLM function were set to 10^{-9} with a limit of 1000 iterations (Pattenden et al., 2003). The GLMs included terms for day of week (indicator variables), and 'season' (a smoothed function of date with seven degrees of freedom per year—based on findings of the NMMAPS mortality reanalysis study; Dominici et al., 2000) in addition to the 12 temperature variables described above. Models also included terms representing lagged black smoke and interactions between black smoke and temperature (Carder et al., 2008). The over-dispersion parameter (estimated from the GLM models) was close to 1 suggesting little additional variation beyond Poisson variation, and as such a simple Poisson model was assumed. For presentation of results, the percentage increase in mortality for standard exposure increments was derived from $(\text{RR}-1) \times 100\%$, where RR was the relative risk derived from $\exp(\beta)$, where β represents calculated GLM coefficients.