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Characterising socio-economic inequalities in exposure to air pollution: A comparison of socio-economic markers and scales of measurement

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ABSTRACT

This study examines traffic-related air pollution in London in relation to area- and individual-level socio-economic position (SEP). Mean air pollution concentrations were generally higher in postcodes of low SEP as classified by small-area markers of deprivation (Index of Multiple Deprivation (IMD) domains) and by the postcode-level ACORN geodemographic marker. There were exceptions, however, including reversed directions of associations in central London and for SEP markers relating to education. ACORN predicted air pollution independently of IMD and explained additional variation at the postcode level, indicating the potential value of using both markers in air pollution epidemiology studies. By contrast, after including IMD and ACORN there remained little relationship between air pollution and individual-level SEP or smoking, suggesting limited residual socio-economic confounding in epidemiological studies with comprehensive area-level adjustment.

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1. Introduction

Exposure to traffic-related air pollution is associated with numerous adverse health effects, including all-cause mortality (Pope et al., 1995; Pope et al., 2002; Hoek et al., 2002; Finkelstein et al., 2004; Krewski et al., 2000), cardiovascular events (Pope et al., 2002; Peters et al., 2004; Tonne et al., 2007; Miller et al., 2007), lung cancer (Pope et al., 2002; Nyberg et al., 2000) and respiratory outcomes in children (Gauderman et al., 2007; Morgenstern et al., 2007). Individuals of low socio-economic position (SEP) may be more exposed to air pollution and also more susceptible to these adverse health effects (O'Neill et al., 2003; Deguen and Zmirou-Navier, 2010; Briggs et al., 2008; Pye et al., 2001; Tonne et al., 2008). Such socio-economic differentials in exposure and health risk can be characterised as a source of environmental injustice, which exacerbates health inequalities via the 'triple jeopardy' of low SEP, polluted environment and impaired health (Jerrett et al., 2001, O'Neill et al., 2003, Northridge et al., 2003).

In air pollution epidemiology research studies, SEP is typically characterised using individual-level and/or small-area-level markers. In the UK, a very commonly used small-area marker is the Index of Multiple Deprivation (IMD (Noble et al., 2004)), which is available at Super Output Area level (containing around 1500 people). The IMD is typically examined as a single summary index of deprivation, although it can also be disaggregated to look at different domains of deprivation. A second less common small-area marker is the ACORN classifier ('A Geodemographic Classification system of Residential Neighbourhoods' (CACI, 2009)), which is available at the postcode level (containing around 50 people). To our knowledge, no previous study has compared the performance of these markers in terms of characterising and adjusting for SEP in epidemiological studies of air pollution and health. It is, however, plausible that they capture different aspects of socio-economic influence. For example, ACORN has a finer geographic resolution than IMD, and also includes additional variables such as age, life stage (e.g. age, children vs. no children, working vs. retired) and 'lifestyle'.

There is also relatively limited evidence on how well such area-level markers perform against individual-level markers of SEP. Many air pollution studies do not have access to individual-level SEP data, and this is frequently cited as a reason for caution in interpreting their findings. Only a few studies, however, have investigated the likely magnitude of residual confounding by individual SEP and/or by smoking status (Naess et al., 2007; Wheeler and Ben-Shlomo, 2005). These studies found that

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adjusting for individual markers of SEP and smoking status added little value after adjusting for area-level SEP.

This paper therefore uses data from London (UK) to (1) characterise in detail the association between air pollution and SEP, comparing different SEP markers and different scales of measurement; and (2) assess the potential for residual confounding in studies lacking individual-level data on SEP and smoking. This paper thereby addresses methodological issues of general relevance for studies investigating air pollution and health, as well as characterizing socio-economic inequalities which are of interest in their own right.

2. Methods

2.1. Setting and participants

We focused upon residential unit postcodes within the orbital M25 motorway of London (UK). These 7-digit postcodes are used for mail delivery and contain a mean of 14 households and 51 individuals. We excluded the 870 postcodes not classified by ACORN, leaving a total of 186,424 postcodes in our analyses. The centroids of these postcodes were nested within 5344 Super Output Areas (SOAs) and 55 boroughs: SOAs contain a mean of around 1500 individuals. For analytical purposes we also defined four zones of London: 'central London' (≤ 5 km from Charing Cross, London's conventional centre); 'inner London' (> 5 km from Charing Cross but in one of the 13 inner London boroughs); 'outer London' (the 20 outer London boroughs); and 'outside London' (the 22 boroughs outside Greater London but with postcodes inside the M25).

Our individual-level analyses used data from the Whitehall II study, an occupational cohort of London civil servants (Marmot and Brunner, 2005). Out of 10,308 civil servants first recruited to the Whitehall study in 1985–1988, 6914 (67.1%) participated in the Whitehall II phase 7 follow-up in 2002–2004. Of these, 3654 Phase 7 participants had current residential postcodes within the M25 and formed the study population for this paper. These 3654 individuals had a mean age of 60.6 years (range 50–74) and were 64% male.

The study was approved by the London School of Hygiene and Tropical Medicine ethics committee, application number 5410.

2.2. Modelled exposure to air pollution

Annual average (2003) nitrogen oxides (NO_x) concentrations were provided by the Environmental Research Group, King's College London. NO_x was used as a surrogate for traffic-related air pollution because it showed more spatial variation within London than the other modelled pollutants (PM_{10} and NO_2). The modelling approach has been described previously (Tonne et al., 2008; Tonne et al., 2009). Briefly, the NO_x contribution for roadways within a 500 m buffer around 31 monitoring locations was modelled using ADMS Roads (CERC, 2003) and OSPM (Berkowicz, 2000) and the contribution from the urban background was modelled using ADMS3. Concentrations from these emission-dispersion models were calibrated by fitting regression models to NO_x measurements from the 31 monitoring sites. The regression model was then applied to predict NO_x concentrations on a 20 m $\times$ 20 m grid. Postcode average NO_x was calculated by averaging the concentrations for all gridpoints within 25 m of the postcode centroid. The correlation between modelled and measured NO_x concentrations was 0.6 at 23 monitoring locations not included in the calibration step.

2.3. Markers of socio-economic position

We used markers of SEP measured at three different scales: the SOA, the postcode and the individual.

2.3.1. Super Output Area-level Index of Multiple Deprivation (IMD)

The Index of Multiple Deprivation (IMD (Noble et al., 2004)) is a weighted composite of small-area data relating to ten domains and subdomains (henceforth 'domains'): income; employment; health; child education; adult education; crime; barriers to housing; barriers to services; indoor environment; and outdoor environment. Data for these domains can also be analysed separately.

Because outdoor environment deprivation is partly based upon modelled concentration of nitrogen dioxide, benzene, sulphur dioxide and particulates, we created an 'IMD-minus-outdoor environment' score. We did this adapting an approach previously used to remove the health domain from the full IMD score (Adams and White, 2006). As when calculating the full IMD score (Annex I in Noble et al., 2004), we standardized and exponentially transformed the non-outdoor environment domains. We then calculated new weights by reallocating the 3% weight of the outdoor environment score across the other domains, in proportion to their original weights (see supplementary material).

2.3.2. Postcode-level ACORN classifier ('A Geodemographic Classification system of Residential Neighbourhoods')

The ACORN classification (CACI, 2009) starts by categorising census output areas using data from the 2001 UK census. Lifestyle/consumer surveys and publically-available data are then used (1) to reclassify postcodes differing substantially from their surrounding area and (2) to update ACORN annually. In this paper we use the ACORN 2003 mid-level categorisation of 17 'groups', ranked by ACORN in order of affluence (details in the Supplementary material).

2.3.3. Individual-level SEP and smoking status from the Whitehall II cohort

Participants in Phase 7 of the Whitehall II cohort (Marmot and Brunner, 2005) provided their current/most recent employment grade at the civil service, classified as clerical/executive officer (lower); higher/senior executive officer (intermediate); and unified grades 1–7 (higher). Participants also provided information on their highest educational attainment, current household income and smoking habits. We also used the participants' current residential postcodes to assign the NO_x, IMD and ACORN measures described above.

2.4. Statistical analysis

Analyses focused on the association between NO_x concentrations and the various markers of SEP, analysed by tabulation and linear regression. As NO_x concentrations were positively skewed, we used log NO_x values as the outcome in regression analyses. For ease of interpretation, we converted the regression coefficients (β_s) into percent increase per unit change in the explanatory factor using the formula $[\exp(\beta)-1]*100$. We standardized all IMD scores using the London-wide means and standard deviations.

We accounted for spatial autocorrelation by fitting three-level random intercept models, of postcodes (or individuals) nested within SOAs nested within boroughs:

$$Y_{ijk} = \beta_0 + \beta_1 x_{1ijk} + \ldots + \beta_p x_{pijk} + B_k + S_{jk} + e_{ijk}$$

where Y_{ijk} is the modelled NO_x concentration for the ith postcode/individual in the jth SOA in the kth borough; $\beta_1 \ldots \beta_p$ are the

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