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Socioeconomic and ethnic inequalities in exposure to air and noise pollution in London

Cathryn Tonne[a,*], Carles Milà[a], Daniela Fecht[b], Mar Alvarez[a], John Gulliver[b], James Smith[c], Sean Beevers[c], H. Ross Anderson[c,d], Frank Kelly[c]

[a] ISGlobal, Universitat Pompeu Fabra, CIBER Epidemiología y Salud Pública, Barcelona, Spain
[b] UK Small Area Health Statistics Unit, MRC-PHE Centre for Environment and Health, Imperial College London, London, UK
[c] Environmental Research Group, MRC-PHE Centre for Environment and Health, Kings College London, London, UK
[d] Population Health Research Institute, St George's, University of London, UK

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ABSTRACT

Background: Transport-related air and noise pollution, exposures linked to adverse health outcomes, varies within cities potentially resulting in exposure inequalities. Relatively little is known regarding inequalities in personal exposure to air pollution or transport-related noise.

Objectives: Our objectives were to quantify socioeconomic and ethnic inequalities in London in 1) air pollution exposure at residence compared to personal exposure; and 2) transport-related noise at residence from different sources.

Methods: We used individual-level data from the London Travel Demand Survey (n = 45,079) between 2006 and 2010. We modeled residential (CMAQ-urban) and personal (London Hybrid Exposure Model) particulate matter < 2.5 μm and nitrogen dioxide (NO_2), road-traffic noise at residence (TRANEX) and identified those within 50 dB noise contours of railways and Heathrow airport. We analyzed relationships between household income, area-level income deprivation and ethnicity with air and noise pollution using quantile and logistic regression.

Results: We observed inverse patterns in inequalities in air pollution when estimated at residence versus personal exposure with respect to household income (categorical, 8 groups). Compared to the lowest income group (< £10,000), the highest group (> £75,000) had lower residential NO_2 (−1.3 (95% CI −2.1, −0.6) μg/m^3 in the 95th exposure quantile) but higher personal NO_2 exposure (1.9 (95% CI 1.6, 2.3) μg/m^3 in the 95th quantile), which was driven largely by transport mode and duration. Inequalities in residential exposure to NO_2 with respect to area-level deprivation were larger at lower exposure quantiles (e.g. estimate for NO_2 5.1 (95% CI 4.6, 5.5) at quantile 0.15 versus 1.9 (95% CI 1.1, 2.6) at quantile 0.95), reflecting low-deprivation, high residential NO_2 areas in the city centre. Air pollution exposure at residence consistently overestimated personal exposure; this overestimation varied with age, household income, and area-level income deprivation. Inequalities in road traffic noise were generally small. In logistic regression models, the odds of living within a 50 dB contour of aircraft noise were highest in individuals with the highest household income, white ethnicity, and with the lowest area-level income deprivation. Odds of living within a 50 dB contour of rail noise were 19% (95% CI 3, 37) higher for black compared to white individuals.

Conclusions: Socioeconomic inequalities in air pollution exposure were different for modeled residential versus personal exposure, which has important implications for environmental justice and confounding in epidemiology studies. Exposure misclassification was dependent on several factors related to health, a potential source of bias in epidemiological studies. Quantile regression revealed that socioeconomic and ethnic inequalities in air pollution are often not uniform across the exposure distribution.

1. Introduction

Transport-related air and noise pollution, environmental exposures linked to a range of adverse health outcomes (Health Effects Institute, 2009; WHO Europe, 2011), varies within cities. This variation may result in exposure inequalities: different socioeconomic and ethnic

* Corresponding author at: ISGlobal, Doctor Aiguader, 88, 08003 Barcelona, Spain.
E-mail address: Cathryn.tonne@isglobal.org (C. Tonne).

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groups being more exposed than others (European Commission, 2016). Socioeconomic and ethnic inequalities in health are well established (Shiels et al., 2017; Stringhini et al., 2017). The unequal distribution of environmental exposures may contribute to these health inequalities where exposures are higher in individuals or communities with lower socioeconomic position or in specific ethnic groups.

Studies from the US show a fairly consistent relationship between individuals or communities of lower socioeconomic position and increased exposure to air pollution (Hajat et al., 2015). Evidence from Europe is mixed (Temam et al., 2017), with some studies indicating non-linear relationships or high exposures in city centres with concentrations of individuals with high socioeconomic position (Goodman et al., 2011; Havard et al., 2009). Within Europe, areas with a high proportion of non-white residents have also been observed to have higher air pollution exposures (Fecht et al., 2015). However, nearly all studies have considered exposure inequalities based on residential exposures, with very few examples based on personal exposure (Jantunen et al., 2000; Rotko et al., 2001), or exposures experienced during commuting (Rivas et al., 2017). In addition, most studies have investigated environmental inequalities at the neighborhood or area-level, while few have investigated exposure inequalities using individual-level socioeconomic or ethnicity data (Hajat et al., 2015; Temam et al., 2017).

Compared to air pollution, fewer studies have investigated inequalities in transport-related noise and most have focused on road-traffic, rather than rail or aircraft noise (European Commission, 2016). The available evidence is inconsistent. Several studies have observed positive associations between road-traffic noise and deprivation (Dale et al., 2015; Havard et al., 2009; Nega et al., 2013); while others have observed the reverse (Havard et al., 2011), or no association (Halonen et al., 2015). A small number of studies in Europe have investigated the relationship between different metrics of deprivation and aircraft noise (Huss et al., 2010; Pelletier et al., 2013). A recent small-area study reported inequalities in environmental noise according to area-level race, racial segregation, and socioeconomic characteristics across the US, but did not differentiate between anthropogenic sources (Casey et al., 2017).

We aim to fill this gap in the literature by considering air pollution exposure inequalities both at residence and using modeled personal exposure as well as noise exposures from multiple sources. Our objectives were to quantify socioeconomic and ethnic inequalities in 1) air pollution exposure at residence compared to personal exposure; and 2) transport-related noise at residence from different sources. Rather than focus only on inequalities in mean exposures, we consider inequalities across the full exposure distribution, providing a more complete picture of inequalities in transport-related environmental exposures than previous studies.

2. Methods

2.1. Study population

The study population was based on individuals who responded to the London Travel Demand Survey (LTDS), conducted by Transport for London to capture data on travel patterns and modal share (Transport for London, 2015). The survey sampled approximately 8000 households per year on a rolling basis and was based on a random sample of households. Data were collected through a face-to-face interview in participants' homes. Respondents were asked about their activities on the previous day and how typical this was of their normal day. Transport for London adjusted the sample for sampling weights and non-response to generate a sample representative of London overall as well as sub-regions of the city. We used LTDS data from 45,079 individuals (20,542 households) who responded to the survey between years 2006–2010, after excluding 4969 individuals (11%) with missing residential postcode, demographic or trip (origin or destination) data (**S Table 1**).

2.2. Air pollution data

The London Hybrid Exposure Model (LHEM) was used to estimate exposure to air pollution (particulate matter < 2.5 μm [$PM_{2.5}$], nitrogen dioxide [NO_2]) of individuals included in the LTDS based on their residential location, trips, mode of transport, and time spent in non-residential locations between trips. The model is described in detail elsewhere (Smith et al., 2016). Briefly, trip start and end coordinates, times of trips, and transport mode are taken from the LTDS. The route between origin and destination was simulated using methods appropriate for each travel mode. Exposure to outdoor air pollution was estimated using the Community Multiscale Air Quality Modeling System (CMAQ-urban), described below (Beevers et al., 2012). To account for penetration of outdoor air indoors, in-building exposures were estimated by applying indoor/outdoor ratios for domestic buildings estimated for each London postcode to the CMAQ-urban estimates (Taylor et al., 2014). In-vehicle exposures were estimated in LHEM using mass-balance equations. Microenvironmental exposures for trips on the London Underground were estimated based on measured concentrations in the London or Paris metro system. Exposures while walking and cycling were estimated based on the CMAQ-urban estimates for the time and location of the trip. Although the model does not fully capture personal exposure from all sources in all microenvironments, for ease of interpretability, we refer to LHEM as an estimate of personal exposure to ambient pollution.

We used CMAQ-urban to predict ambient air pollution concentrations at place of residence. CMAQ-urban couples the Weather Research and Forecasting meteorological model with the Atmospheric Dispersion Modeling System roads model. We generated annual average concentrations of $PM_{2.5}$ and NO_2 for each hour of the day for the year 2011 at 20 m × 20 m resolution (Taylor et al., 2014). Residential air pollution estimates are based on the 24 h mean concentration (**S-Fig. 1**).

2.3. Road traffic noise

Annual road traffic noise for years 2003–10 was modeled at the geometric centroid for all ~190,000 London postcodes using the TRAffic Noise EXposure (TRANEX) model (Gulliver et al., 2015). Briefly, the model uses detailed information on traffic flows and speeds for each year, land cover, and heights of individual buildings. We used $L_{Aeq,24h}$ (average over the hours 0:00 to23:59), because it covers the same time period as the residential air pollution estimates; however, Spearman correlations with other noise metrics including L_{night} and $L_{Aeq,16h}$ were > 0.99. Individuals were assigned the modeled noise levels for their postcode (approximately 12 households per postcode). Less than 1% of postcodes were outside of the TRANEX model domain and could not be linked.

2.4. Rail and airport noise

We identified individuals whose residential postcode was within the 50 dB noise contours of over-ground railways and Heathrow airport. Noise contours came from strategic noise mapping under the first round of the Environmental Noise Directive. Data for over-ground railways were from Department for Environment, Food and Rural Affairs, supplied by Extrium Ltd. Aircraft noise from Heathrow airport was derived from annual average contours (2001) supplied by the Civil Aviation Authority.

2.5. Sociodemographic data

Self-reported age, household income, and ethnicity were available from the LTDS. Ethnicity was collapsed into four ethnic groups: white (white – British, white – Irish, other white), Asian (Asian or Asian