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Double burden of deprivation and high concentrations of ambient air pollution at the neighbourhood scale in Montreal, Canada

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ABSTRACT

Some neighbourhoods in urban areas are characterised by concentrations of socially and materially deprived populations. Additionally, levels of ambient air pollution in a city can be variable at the local scale and can create disparities in air quality between neighbourhoods. Socioeconomic and physical characteristics of neighbourhood environments can affect the health and well-being of local residents. In this paper we identify whether neighbourhoods in Montreal, Canada characterised by social and material deprivation have higher levels of ambient air pollution than do others.

We collected two-week integrated samples of nitrogen dioxide (NO_2) at 133 sites in Montreal during three seasons between 2005 and 2006. We used these data in a geographic information system, along with data describing characteristics of land use, roads, and traffic, to create a spatial model of predicted mean annual concentrations of NO_2 across Montreal. Next, we collected neighbourhood socioeconomic information for 501 census tracts and overlaid their boundaries on the pollution surface. We calculated Pearson correlation coefficients and 95% confidence intervals (CI) between neighbourhood-level indicators of deprivation and levels of ambient NO_2.

We found associations between concentrations of NO_2 and neighbourhood-level indicators of material deprivation, including median household income, and with indicators of social deprivation, including proportion of people living alone. We identified specific neighbourhoods that were characterised by a double burden of high levels of deprivation and high concentrations of ambient NO_2. Because of the particular social geography in Montreal, we found that not all deprived neighbourhoods had high levels of pollution and that some affluent neighbourhoods in the downtown core had high levels. Our results underscore the importance of considering social contexts in interpreting general associations between social and environmental risks to population health.

Introduction

The concept of the social gradient in health, namely that individuals of lower socioeconomic position tend to have poorer health than more advantaged individuals, is well-established (Lynch, Davey Smith, Harper, & Bainbridge, 2006; Marmot, 2004; Wilkins, Berthelot, & Ng, 2002; Wilkins, Tjepkema, Mustard, & Choiniere, 2008). Social gradients in health outcomes have been observed for all-cause mortality and for most chronic diseases across the developed world, regardless of how socioeconomic status (SES) or deprivation is measured (Wilkinson & Marmot, 2003). Certain characteristics of both physical and social environments influence gradients in health.

Spatial variability of air pollution and associated health effects

Ambient air pollution is an example of an environmental hazard that may influence gradients in health and that can be highly variable at local scales. For example, Hewitt (1991) observed in Lancaster, UK, differences in average annual levels of ambient nitrogen dioxide (NO_2) of more than 50 $\mu g/m^3$ between sampling locations less than 50 m apart from each other. Numerous studies have shown that spatial variability of levels of ambient air pollution can be greater between different neighbourhoods within cities than those between cities (Briggs et al., 2000; Jerrett et al., 2005; Zhu, Hinds, Kim, Shen, & Sioutas, 2002). Intra-urban variability in ambient air pollution may be caused by a variety of factors, including how pollutants mix locally in the air, and factors that

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affect dispersion of pollution (e.g., local wind patterns (Seaman, 2000)), land use, and patterns of traffic.

Vehicular traffic is a primary local contributor to urban air pollution through direct emissions of nitrogen oxides (NO_x), carbon monoxide, carbon dioxide, sulphur dioxide, volatile organic compounds (VOCs), polycyclic aromatic hydrocarbons, and particulates. In metropolitan Montreal, Canada, for example, 85% of emissions of NO_x and 43% of VOCs have been attributed to transportation (King, Morency, & Lapierre, 2005). Nitrogen dioxide is recognized as a good indicator of traffic-related pollution due to its demonstrated co-locational association with other traffic-related pollutants (Beckerman et al., 2008; Brunekreef & Holgate, 2002; Nieuwenhuijsen, 2000; Wheeler, Smith-Doiron, Xu, Gilbert, & Brook, 2008). In a recent review of the effects of NO_2 on human health, Latza, Gerdes, and Baur (2008) found evidence that exposure to mean annual levels below 22 ppb was associated with respiratory symptoms and diseases, hospital admissions, mortality, and otitis media. In a separate systematic review Chen, Goldberg, and Villeneuve (2008) reported associations between an increase of 10 $\mu g/m^3$ in ambient NO_2 and incidence or mortality from respiratory diseases (pooled relative risk (RR) = 1.16, 95% CI: 1.06–1.26) and with cardiovascular mortality (RR = 1.02, 95% CI: 0.98–1.07). It must be acknowledged, however, that due to the co-locational association with other pollutants, it remains unclear to what extent the health affects observed are indeed associated with exposure to NO_2 as opposed to the other pollutants or the complex mixture that makes up ambient air.

Exposure to ambient air pollution generally is associated with a wide variety of negative health outcomes. Some of these health effects are acute, which are observed shortly after exposure (e.g., headaches, nausea, upper-respiratory infections, daily hospitalizations) and others are chronic, or long-term, which develop from continuous exposures throughout life. Several large cohort studies have shown positive associations between long-term exposure to air pollution and mortality rates from cardiopulmonary diseases and lung cancer, after accounting for smoking and other risk factors (Dockery et al., 1993; Pope et al., 1995, 2002). A systematic review conducted by one of us (Chen et al., 2008) has shown, for example, that long-term exposure to fine particles ($PM_{2.5}$) increases the risk of non-accidental mortality by 6% per a 10 $\mu g/m^3$ increase, independent of age, gender, and geographic region. Judek, Jessiman, Stieb, and Vet (2004) estimated that approximately 5900 deaths were caused annually by combined short- and long-term exposure to air pollution in eight Canadian cities, including over 1500 in the city of Montreal alone. This number of premature deaths in eight major Canadian cities is more than the amount estimated nationally for each of breast cancer, prostate cancer, pancreatic cancer (Canadian Cancer Society, 2008), and motor vehicle accidents (Ramaage-Morin, 2008).

Double burden of deprivation and exposure to air pollution

The concept of deprivation – as distinct from poverty, which refers more specifically to a lack of financial resources – emerged in Britain in the 1980s from a long tradition of analyzing social inequalities in health (Pampalon & Raymond, 2002). Townsend (1987, p. 125) defined deprivation as "a state of observable and demonstrable disadvantage relative to the local community or the wider society or nation to which an individual, family or group belongs." Some individuals or households may exhibit multiple dimensions of deprivation, such as suffering from a low income, as well as lacking in participation in typical roles, relationships, and responsibilities of membership in society.

Townsend (1987) differentiated between two main forms of deprivation, namely, *material* (i.e., lacking in basic material goods and conveniences of modern life, such as a safe place to live, adequate diet, and basic household amenities), and *social* (i.e., lacking in social relationships with members of one's family, community, or workplace). Both of these forms of deprivation have important implications for public health. Pampalon and Raymond (2002) provide a brief review of the links between living in deprived neighbourhoods and mortality and with morbidity from a wide variety of health outcomes.

Low educational attainment, which is one indicator of deprivation, has been shown to have an effect on the social gradient in health. For example, Pope et al. (2002) found that the association with particulate pollution was stronger for both cardiopulmonary and lung cancer mortality among individuals with lower levels of education. As reviewed by O'Neill et al. (2003) and Laurent, Bard, Filleul, and Segala (2007), there is evidence that air pollution contributes to creating or accentuating socioeconomic gradients in air pollution-related health outcomes and in premature mortality. O'Neill et al. (2003) outline three possible mechanisms to explain how exposure to air pollution may contribute to greater health effects among individuals of lower SES:

1) lower SES may increase susceptibility to air pollution-related health risks directly through increased levels of psychosocial stress, limited access to health care, or increased likelihood of living in lower quality housing;
2) some health conditions (e.g., asthma, diabetes, and cardiovascular diseases (Goldberg, Burnett, Yale, Valois, & Brook, 2006)), behaviours (e.g., smoking), and genetic traits that increase susceptibility to effects of air pollution are distributed differentially by SES; and,
3) populations with low SES may have more frequent or more intense exposures to air pollution than those with high SES due to environmental inequalities.

Differentials in exposure by SES are perhaps the least studied of the three mechanisms outlined above through which exposure to air pollution may contribute to the social gradient in air pollution-related health outcomes. Ambient exposure to air pollution at the household-level is an important component of daily exposure. The major factors that determine where people choose to live include the accessibility and availability of services and amenities, the proximity to work or school, and affordability of housing. In this context, land use restrictions and real estate costs are important factors leading to unequal distributions of exposure by SES. For example, industrial facilities that produce pollution are located typically away from affluent neighbourhoods because of zoning restrictions, the higher costs of land, and prevailing winds. Individuals that are constrained financially face limited choices of where to live and they may reside near sources of pollution, including near roads with high traffic density, industrial facilities, waste disposal facilities, or airports (Gunier, Hertz, Von, & Reynolds, 2003; Perlin, Sexton, & Wong, 1999). In affluent households, however, people have a greater ability to avoid living in close proximity to undesirable areas.

There is increasing evidence that residents in some neighbourhoods in urban areas in North America and Europe face the double burden of lower SES and elevated exposure to air pollution (Havard, Deguen, Zmirou-Navier, Schillinger & Bard, 2009; Jerrett et al., 2001; Naess, Piro, Nafstad, Smith, & Leyland, 2007; Premji, Bertrand, Smargiassi, & Daniel, 2007). In their comprehensive analysis of environmental inequity in Great Britain, Briggs, Abellan, and Fecht (2008) found generally strong, positive associations between low SES and local levels of ambient air pollution. In some cases, however, these authors found non-linear, J-shaped, and U-shaped associations, thus highlighting the fact that simple correlations may mask some of the complexities in the associations