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Neighborhood walkability and particulate air pollution in a nationwide cohort of women

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ABSTRACT

Background: Features of neighborhoods associated with walkability (i.e., connectivity, accessibility, and density) may also be correlated with levels of ambient air pollution, which would attenuate the health benefits of walkability.
Objectives: We examined the relationship between neighborhood walkability and ambient air pollution in a cross-sectional analysis of a cohort study spanning the entire United States using residence-level exposure assessment for ambient air pollution and the built environment.
Methods: Using data from the Nurses' Health Study, we used linear regression to estimate the association between a neighborhood walkability index, combining neighborhood intersection count, business count, and population density (defined from Census data, *info*USA business data, and StreetMap USA data), and air pollution, defined from a GIS-based spatiotemporal $PM_{2.5}$ model.
Results: After adjustment for Census tract median income, median home value, and percent with no high school education, the highest tertile of walkability index, intersection count, business count, and population density was associated with a with 1.58 (95% CI 1.54, 1.62), 1.20 (95% CI 1.16, 1.24), 1.31 (95% CI 1.27, 1.35), and 1.84 (95% CI 1.80, 1.88) μg/m^3 higher level of $PM_{2.5}$ respectively, compared to the lowest tertile. Results varied somewhat by neighborhood socioeconomic status and greatly by region.
Conclusions: This nationwide analysis showed a positive relationship between neighborhood walkability and modeled air pollution levels, which were consistent after adjustment for neighborhood-level socioeconomic status. Regional differences in the air pollution-walkability relationship demonstrate that there are factors that vary from region to region that allow for walkable neighborhoods with low levels of air pollution.

1. Introduction

The complex built environments in which we live create a dynamic interplay between factors that create both opportunities and barriers to health. Research on the built environment and health is growing, with a majority of the focus on its influence on walking (Saelens et al. 2003; Saelens and Handy, 2008). Walking presents a low-cost, low-impact source of routine physical activity that can be undertaken by individuals at any life stage and at all levels of socioeconomic status. The health benefits of physical activity have been well documented, yet less than half (48%) of all adults meet the Surgeon General's recommended 30 min of moderate intensity physical activity on most days of the week (Centers for Disease Control and Prevention, 2010; Besser and Dannenberg, 2005). A recent study by Lee et al. (2012) estimates that physical inactivity contributes to 6% of the global burden of disease from coronary heart disease, 7% of type 2 diabetes, 10% of breast cancer, 10% of colon cancer, 9% of premature mortality. If inactivity were decreased by 10–25%, between 533,000 and 1.3 million deaths could be averted every year.

Although many environmental factors have been explored, population density, access to facilities, and street connectivity are geographic information systems (GIS)-based measures of the built environment that are consistently associated with walking (Brownson et al., 2009; McCormack and Shiell, 2011; Sallis et al., 2012). These associations have been observed in numerous settings across the US and abroad, as well as in urban (Sallis et al., 2009) and rural settings (Frost et al., 2010). We have examined associations between these measures and walking within the

Abbreviations: CI, confidence interval; GIS, geographic information systems; HS, high school; IHD, ischemic heart disease; NHS, Nurses' Health Study; $PM_{2.5}$, particulate matter with an aerodynamic diameter less than 2.5 μm; SD, standard deviation; SES, socioeconomic status

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Nurses' Health Studies cohorts and found that levels of recreational walking were higher in more accessible neighborhoods with more connected streets (James et al., 2014). While numerous studies have demonstrated that individuals living in areas with higher residential density, many destinations in close proximity, and more connected street networks tend to walk more (Sallis et al., 2012), research in the area of the built environment rarely addresses concurrent air pollution exposures. Particulate air pollution has been well-characterized as a risk factor for chronic disease and mortality (Hoek et al., 2013; Lee et al., 2014; Pope and Dockery, 2006). While there are multiple sources of particulate air pollution, such as long range transport from power plants, source apportionment studies demonstrate that vehicular emissions are a source of particulate matter concentrations (Hasheminassab et al., 2014). Features of neighborhoods that are associated with walkability (e.g. density, accessibility, and connectivity) are also predictors of vehicular air pollution levels, including particulate matter and NO_2 (Ryan and LeMasters, 2007). While these neighborhood features do not explain all variability in vehicular or particulate air pollution concentrations, they may contribute to important differences in exposure across populations. Although per capita emissions may be lower in more walkable neighborhoods due to lower levels of individual vehicle use, a higher density of individuals and vehicles in a walkable neighborhood may lead to higher concentrations of traffic-related air pollution. Therefore, while levels of walking may be higher among residents of more walkable neighborhoods, increased air pollution exposure for these individuals could attenuate the health benefits of this increased physical activity.

A recent set of studies has begun to explore the potential tradeoffs between walkability and air pollution and researchers have adopted an array of approaches to tackle this complex issue (de Nazelle et al., 2011; Hankey et al., 2012; Marshall et al., 2009). For instance, Hankey et al. (2012) showed that $PM_{2.5}$ was on average 3 $\mu g/m^3$ higher in high walkability neighborhoods compared to low walkability neighborhoods in southern California. They then applied a risk assessment framework that predicted while physical activity benefits of walkable neighborhoods would produce a health benefit (7 fewer ischemic heart disease deaths/100,000/year in high vs low walkability neighborhoods), this benefit would be counteracted by higher exposure to air pollution (9 more ischemic heart disease deaths/100,000/year in high vs low walkability neighborhoods). These studies have also demonstrated that the relationship between walkability and air pollution differed according to neighborhood socioeconomic status, showing that the proportion of postal codes with low walkability and low air pollution was six times greater for the highest-income versus lowest income postal codes (Marshall et al. 2009). Although a comprehensive understanding of the tradeoffs between air pollution exposure and walkability is unclear, these studies have demonstrated a relationship between air pollution and neighborhood walkability measures with potential implications for chronic disease. However, studies on this topic have been limited to specific geographic areas, such as a single city or region, and have not investigated potentially important variations in the relationship between air pollution and the built environment between regions.

In the current study we built on the literature examining the relationship between neighborhood walkability and ambient air pollution in a nationwide cross-sectional analysis of a cohort study. Our primary objective was to investigate the relation between walkability and air pollution data using residence-level exposure assessment for ambient air pollution and the built environment. Our secondary objectives were to examine whether these relationships varied according to neighborhood-level socioeconomic status and region.

2. Methods

2.1. Population

We used data from the Nurses' Health Study (NHS), a nationwide prospective cohort assessing a wide variety of risk factors for chronic disease among women. In 1976, 121,700 female registered nurses ages 30–55 years from 11 states (New York, California, Pennsylvania, Ohio, Massachusetts, New Jersey, Michigan, Texas, Florida, Connecticut, and Maryland) returned an initial questionnaire that ascertained a variety of health-related exposures and medical diagnoses. The cohort has been continuously followed with biennial questionnaires as participants changed addresses and moved throughout the country. Response rates at each two-year questionnaire cycle have consistently been $\sim$90%. Data for this cross-sectional analysis were taken from 2006, the most recent year for which air pollution and walkability data are available. All available residential addresses in 2006 were geocoded to obtain latitude and longitude. Approximately 90% were successfully matched to the street address or zip plus 4 centroid (typically encompassing one side of a street segment) level. For the current analyses we included all women who completed the 2006 questionnaire, lived in the continental US, and had a street segment or zip code plus-4 level geocoding match.

2.2. Built environment

Using Census data and commercially available geographic information systems (GIS) data, we created residence-level measures of population density, business counts (as a proxy for accessibility), and intersection counts (as a proxy for street connectivity) linked to the participants' geocoded 2006 mailing addresses.

Population density was calculated based on the 2000 US Census reported population density in the US Census tract of residence in 2006.

To develop business count and intersection count measures, we created 1200 m line-based network buffers around each home address. For line-based network buffers, we drew lines along the road network up 1200 m, then created a 50 m polygon around each line. An example of a network buffer is shown in Fig. 1 (For more information, see James et al. (2014)).

Briefly, we used ArcGIS software (Redlands, CA) to identify the street network within 1200 m from each participant's mailing address and then included a 50 m buffer on either side of the road. Interstates and ramps were excluded from the networks, as we were interested in walkable streets only. The rationale for using a line-based network buffer versus a polygon-based network buffer was to restrict the analysis to areas close to roads that people can access by walking (Oliver et al., 2007). We then constructed the following measures.

Business counts were measured by the counts of all stores, facilities, and services in a participant's network buffer using the commercially available 2009 *info*USA spatial database on "points of interest", which includes grocery stores, restaurants, banks, hotels, hospitals, libraries, etc. (Fig. 2). *info*USA maintains and adds to their database by referencing several sources including directory listings such as Yellow Pages 10Ks and Securities and Exchange Commission information; federal, state, and municipal government data; and information from the US Postal Service. After telephone verification, these addresses were geocoded. The quality of the local address system varies; address matching is better in urban areas that use street-level address systems than in rural areas. Overall, 84.3% of the points of interest were geocoded at the address level (ESRI, 2008), and we restricted analyses to these points. Our research team performed a small validation study of over 400