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Predicting urban design effects on physical activity and public health: A case study

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ABSTRACT

With increasing global concerns about obesity and related health effects, tools to predict how urban form affects population physical activity and health are needed. However, such tools have not been well established. This article develops a computer simulation model for forecasting the health effects of urban features that promote walking. The article demonstrates the model using a proposed small-area plan for a neighborhood of 10,400 residents in Raleigh, North Carolina, one of the fastest-growing and most sprawling U.S. cities. The simulation model predicts that the plan would increase average daily time spent walking for transportation by 17 min. As a result, annual deaths from all causes are predicted to decrease by 5.5%. Annual new cases of diabetes, coronary heart disease, stroke, and hypertension are predicted to decline by 1.9%, 2.3%, 1.3%, and 1.6%, respectively. The present value of these health benefits is $21,000 per resident.

1. Introduction

Over the past decade, the role of the built environment in escalating obesity and chronic disease rates has been increasingly recognized (Jackson et al., 2013; Jackson, 2003; Papas et al., 2007; Adams et al., 2011; Kerr et al., 2007; MacDonald et al., 2010; Furie and Desai, 2012; Sallis et al., 2012). As a result, public health practitioners have recommended using health impact assessment (HIA) to focus the attention of city and transportation planners on the health consequences of their decisions (Wernham, 2011; Negev et al., 2012; Bhatia and Corburn, 2011; National Research Council, 2011; Hoehner et al., 2012; Bourcier et al., 2014). As an example, during 1999–2012, at least 34 HIAs of urban and transportation planning projects were completed in the United States (Supplementary file, Table S1).

Most U.S. HIAs follow a process recommended by the U.S. National Academy of Sciences, which also is consistent with global HIA practice (National Research Council, 2011). The recommended process includes an assessment step, which "analyzes and characterizes beneficial and adverse health effects of the proposal and each alternative." However, to our knowledge, no U.S. HIAs of urban planning projects have quantified expected changes in population health as mediated by physical activity (Dannenberg et al., 2012; Bhatia and Seto, 2011). Recent systematic reviews have identified a small number of U.S. academic studies that considered costs and benefits of projects to promote bicycling and walking, but none of these involved developing a predictive model to support a formal HIA (Doorley et al., 2015; Mueller et al., 2015). Many formal U.S. HIAs have identified physical activity as a key health determinant (Supplementary file, Table S1), yet their analyses are limited to qualitative discussions of whether health impacts are expected to be beneficial, detrimental, or neutral. To fill the gap in analytical methods for HIAs, this article develops and then demonstrates an approach for quantifying population physical activity and health effects of different urban designs.

We constructed a computer model that simulates time spent walking for transportation by each resident of a neighborhood as a function of multiple urban design variables (including intersection density, land-use mix, residential density, and retail floor area)

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shown in previous epidemiologic studies to be associated with transportation walking (Frank et al., 2010; Sallis et al., 2009). For each simulated resident, the model then projects the corresponding effect of transportation walking on the risk of premature mortality, diabetes, coronary heart disease (CHD), stroke, and hypertension.

We demonstrated the model by applying it to support an HIA of a new small-area plan for a neighborhood in Raleigh, North Carolina (NC). In 2014, the United Nations ranked the Raleigh area as the second-fastest growing urban agglomeration in the United States (United Nations Department of Economic and Social Affairs, 2014). Until recently, growth in Raleigh was largely unchecked, and as a result the city was referred to by some as “Sprawleigh” (Goldberg, 2011). However, over the past several years, Raleigh has developed a new city plan intended to increase population density and limit sprawl.

Like many post-World War II neighborhoods in the United States, the neighborhood for which we demonstrate the HIA is characterized by low-density, auto-dependent development. Known as the “Blue Ridge Road Corridor” (BRRC) because it is bisected by Blue Ridge Road, the neighborhood is used not only by residents but also by employees and visitors to access a number of area attractions, including the NC Art Museum, NC Fairgrounds, PNC Arena, Rex Healthcare Center, and NC State University College of Veterinary Medicine. However, the neighborhood lacks pedestrian infrastructure (Supplementary file, Figs. S1–S3) and, apart from the main attractions, has few retailers. The limited local road network channels much of the traffic onto Blue Ridge Road.

One of us (S. Levin), a BRRC resident and physician, has observed a rise in obesity and chronic diseases among patients over the past two decades. This observation led to the establishment of a stakeholder group of neighborhood residents and landowners to advocate for change. In turn, the Raleigh Department of City Planning commissioned a new small-area plan and an HIA to analyze its potential health effects. The plan includes several features designed to convert the corridor into a pedestrian-friendly community.

Here, we show how our new simulation model can be used to quantify the health benefits of investing in implementation of the small-area plan. Specifically, one objective of this study was to simulate the potential effects of the new small-area plan on the incidence rates of premature mortality and new cases of diabetes, CHD, stroke, and hypertension over a 25-year period, a typical planning period for capital investment projects. The study also calculated the economic impacts of these avoided cases. An additional objective was to demonstrate a method for quantifying health impacts of new urban small-area plans that could be readily adapted to support future HIAs in other communities.

2. Methods

The simulation model (encoded in *Analytica* v. 4.5, Lumina Decision Systems, Los Gatos, Calif.) follows the framework of the World Health Organization (WHO) Health Economic Assessment Tools (HEAT) Tools for Walking and Cycling (Kahlmeier et al., 2011; Kahlmeier et al., 2014), but it builds on this framework in several important ways. First, it uses data on built environment features to estimate time spent walking for transportation, whereas the HEAT method relies on user-defined estimates of walking time. Second, it estimates chronic disease outcomes in addition to premature mortality. Third, it quantifies uncertainty via Monte Carlo simulation. Consistent with WHO recommendations, the model assumes that full benefits will begin accruing five years after completion (Kahlmeier et al., 2011). For the case study, we assume the small-area plan will be implemented by 2023, and we calculate health outcomes avoided during 2028–2048, consistent with the 20- to 30-year horizon often used in capital investment planning.

2.1. Health outcome selection

We selected for analysis health outcomes shown in previous epidemiologic studies to be associated with walking for transportation and for which estimates of relative risks of the outcome as a function of time spent walking for transportation were available as of the end of 2012, the year during which scoping of the HIA project occurred. At the time of project scoping, such information was available for premature mortality, CHD, stroke, hypertension, and diabetes. Although physical activity has been positively associated with reduced risks of other health outcomes (e.g., breast cancer), no studies specifically associating these outcomes with transportation walking were available when health outcomes were selected for inclusion in the HIA.

2.2. Health impact estimation

The HIA model carries out four steps:

Step 1: Simulate current transportation walking time. Current transportation walking time of each BRRC resident is simulated as a nonparametric probability distribution derived from 386 responses to an IRB-approved survey mailed to 1200 randomly selected BRRC residents in summer 2012. To estimate transportation walking for each respondent, the survey used questions drawn from the International Physical Activity Questionnaire (Supplementary file, Table S2) (IPAQ Group, 2002).

Step 2: Simulate changes in transportation walking time if small-area plan is implemented. For each simulated resident, the model predicts changes in transportation walking time as a function of the walkability score, a measure developed by Frank et al. (2010). Previous research has documented that the walkability score provides a robust indicator of how different urban designs affect transportation walking time, with the magnitude of effects depending in part on household income (Adams et al., 2011; Frank et al., 2010; Sallis et al., 2009; Van Dyck et al., 2010; Frank et al., 2005). The walkability score is computed from

$$\begin{aligned} \textit{Walkability Score} = {} & (2 \times Z_{intersection}) + (Z_{residential}) + (Z_{FAR}) \\ & + (Z_{land-use}) \end{aligned} \tag{1}$$

where the Z variables represent normalized versions of intersection density ($Z_{intersection}$), the number of intersections divided by land area; residential density ($Z_{residential}$), the number of housing units divided by the residential land area; retail floor area (Z_{FAR}), the square footage of retail floor area divided by the square footage of land devoted to retail use; and land-use diversity ($Z_{land\text{-}use}$), computed as described in Cervero and Kockelman (1997). We computed raw values of each of the four component variables in Eq. (1) for the current and the redesigned BRRC using data compiled by the Raleigh Urban Design Center (Supplementary file, Table S3) and normalized them relative to built environment data in Sallis et al. (2009).

The model estimates a probability distribution of transportation walking under the redesigned BRRC, $f_{new}(w)$, according to

$$f_{new}(w) = WF \times f_{current}(w) \tag{2}$$

where *WF* is the ratio of transportation walking time measured by Sallis et al., (2009) in neighborhoods with walkability scores and median household incomes similar to those under the redesigned BRRC to that in neighborhoods with walkability scores and household incomes similar to those of the current BRRC (Supplementary file, Table S4). *WF* is approximately normally distributed with mean = 2.3 and standard deviation (SD) = 0.20.