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Longitudinal associations between neighborhood-level street network with walking, bicycling, and jogging: The CARDIA study

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ABSTRACT

Objective: To investigate the differential association between neighborhood-level street network with walking, bicycling, and jogging by urbanicity and gender.
Methods: We used prospective data from 4 repeated exams on 5115 young adults recruited in 1985–1986, followed through 2000–2001, with self-reported walking, bicycling, and jogging. Using a Geographic Information System, we spatially and temporally linked time-varying residential locations to street network data within a 1 km Euclidean buffer. Two-part marginal effect modeling assessed longitudinal associations between neighborhood-level street network with walking, bicycling, and jogging, by urbanicity and gender, controlling for time-varying individual- and census-level covariates.
Results: Neighborhood street density was positively associated with walking, bicycling, and jogging in low urbanicity areas, but in middle and high urbanicity areas, these associations became null (men) or inverse (women).
Conclusion: Characteristics of neighborhood streets may influence adult residents' walking, bicycling, and jogging, particularly in less urban areas. This research may inform policy efforts to encourage physical activity.

1. Introduction

Owing to minimal impact of behavioral interventions on increasing physical activity (PA) (Ogilvie et al., 2004), recent work has turned to environmental factors, such as street network, an important dimension of urban form, as intervention targets (Owen et al., 2004). Findings in this area suggest that better street connectivity, indicated by more intersections, less dead end streets, more streets, and smaller blocks, leads to more pedestrian travel, generally by reducing travel distance and providing a wide range of possible routes (Berrigan et al., 2010; Braza et al., 2004; Forsyth et al., 2008; Frank et al., 2003; Saelens et al., 2003). However, the literature on street networks and health outcomes is dominated by cross-sectional designs and yields inconsistent findings (Boer et al., 2007; Duncan and Mummery, 2005; Ewing, 2005; Frank et al., 2004; Lovasi et al., 2008; Oakes et al., 2007; Smith et al., 2008; Trost et al., 2002).

Street networks are highly complex in terms of dimensions that might influence behavior. Following the constructs described by Rodrigue et al. (2006), street networks can be measured in the following three dimensions: (1) intersection density, a widely used indicator of basic structural properties (Doyle et al., 2006; Frank et al., 2006; Li et al., 2005); (2) link to node ratio, an indicator of the structural properties of the network; and (3) road type/classification, which represents the hierarchy of linkages across the street network, ranging from local roads (Carver et al., 2010) to highways.

Further, the literature on street networks and behavior generally comes from studies in single metropolitan areas (Duncan and Mummery, 2005; Frank et al., 2004; Oakes et al., 2007), thus resulting in little understanding of how the relationship between neighborhood-level street network and physical activity varies across diverse environmental contexts. Urban, suburban, and rural areas may have different land use and street patterns, ranging from urban gridded streets to suburban cul-de-sacs, which may differentially impact physical activity that

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takes place in streets, such as walking, bicycling, and jogging. Yet, few studies have the geographic variation necessary to capture differences in walking, bicycling, and jogging across different environmental settings (Riva et al., 2009). Further, some evidence suggests that such relationships may vary by gender, with economic and social environment aspects relatively more important for men, whereas built environment factors are more salient for women (Grafova et al., 2008). Others have found sprawl related to BMI among men only (Ross et al., 2007). In general, findings are mixed and all are cross-sectional (Frank et al., 2004, 2008).

Our objective is to investigate the relationship between neighborhood-level street network and leisure-time walking, bicycling, and jogging, and how this relationship varies across urbanicity and gender. We capitalize upon 15-year longitudinal data from the Coronary Artery Risk Development in Young Adults (CARDIA) study, including longitudinal physical activity data as well as longitudinal street network data that are spatially and temporally via a Geographic Information Systems (GIS) to time-varying residential location of study participants.

2. Participants and methods

2.1. Study sample

CARDIA is a population-based prospective epidemiologic study of the evolution of cardiovascular risk factors among young adults. At baseline (1985–1986), 5115 eligible participants, aged 18–30 years, were enrolled with balance according to race, gender, education high school or less and more than high school), and age (18–24 and 25–30) from the populations of Birmingham, AL; Chicago, IL; Minneapolis, MN; and Oakland, CA. Specific recruitment procedures were described elsewhere (Friedman et al., 1988). Seven repeated examinations were conducted. For the current study, we use data from: 1985–1986 (baseline), 1992–1993 (year 7), 1995–1996 (year 10), and 2000–2001 (year 15), with retention rates of 90%, 79%, and 74%, respectively.

The analysis sample includes participants with complete data and without significant physical disabilities. Among 20,460 observations across the four exam years, 19.0% (obs = 3900) were excluded from analysis, mostly due to sample attrition (obs = 3643), missing outcome data (obs = 146), missing environmental data (obs = 2), or statistical control variables (obs = 109). A range of 5–14% of respondents moved to a new state, and 11–27% moved to a new county between exam years during follow-up. Despite starting at baseline in the four US metropolitan areas, by 2000–2001 the CARDIA participants were located across 48 states, 1 federal district, 1 territory, 529 Counties, and 3805 Census Tracts.

All CARDIA participants had residential street addresses recorded at each exam year, which we geocoded and temporally and spatially linked with contemporaneous data on environmental factors derived from a series of public and commercially available data.

2.2. Exposure and outcome measures

2.2.1. Main exposure: neighborhood-level street network within 1 km Euclidean buffer

The 1 km Euclidean buffer (circle of 1 km radius) around each respondent's residential street address at each time period represents the immediate residential neighborhood to capture pedestrian activity (Hoehner et al., 2003; Lee and Moudon, 2004) and is an empirically determined easy walking distance (Jago et al., 2005; Timperio et al., 2006) of around 12–15 min walk at 4–5 km/h. Thus, the Euclidean buffer provides a comparable geographic area comparison as it relates to walking distance over time and across more and less urban areas, a major focus of our analysis.

Unfortunately detailed and accurate street network data were not equally available across all time points, thus necessitating use of only two time periods for street data, which were spatially and temporally linked to residential locations: StreetMap 2000 data for exam years 0, 7, and 10 and from the enhanced product StreetMap Pro 2003 data for exam year 15, both from ESRI, Redlands, CA. StreetMap data were the highest quality data available and provided comparability over the full study, albeit with the limitation of only 2000 and 2003 time periods and the fortune that the CARDIA cities were fairly established with little changes in street network over time. Road type/classification was extracted from TIGER/line™ files.

Following Rodrigue et al. (2006), we used three measures of street network: (1) intersection density as a basic structural property, (2) link-node ratio as a derived structural property, and (3) road type/classification, which represents the hierarchy of linkages across the street network. We describe these measures below and provide examples in Fig. 1.

Street connectivity: higher street connectivity is defined as high number of intersections, few dead end streets, more streets, and smaller blocks. We hypothesized greater walking, bicycling, and jogging in areas with greater street connectivity. Using the StreetMap data, we identified intersections and based connectivity on the number of unique street connections at each intersection. We measured two dimensions of street connectivity: (1) *intersection density* is calculated as number of intersections with 3 or more unique intersecting streets (true intersections) in buffer divided by buffer area (3.14 km^2 across all participants), yielding a comparable measure to other studies. (2) *Link-node ratio* (also known as beta index) is an index of connectivity and equals to the number of links divided by the number of nodes in buffer, where links = street segments (continuous street without interruption of intersection or cul-de-sac); nodes = intersections or cul-de-sacs (Fig. 1). Higher values of intersection density and link-node ratio reflect higher level of street connectivity, largely through the provision of many possible direct routes (links) across the possible intersections (nodes) within the 1 km buffer.

Characteristics of local roads were derived from TIGER/line™ files road classifications. Detailed descriptions can be accessed at http://www.census.gov/geo/www/tiger/appendxe.asc. We measure more walkable, local roads using the A4x category 'local, neighborhood, and rural roads' relative to highways and other vehicle-friendly roads (A0x: roads with major category unknown, A1x: interstate highways, A2x: US and State highways, A3x: State and county highways, A5x: vehicular trails, and A6x: traffic circles and access ramps). We characterized local roads in two dimensions: (1) *density of local roads*: as total length of local roads within the 1 km buffer and (2) *proportion of local relative to total roads*: as the proportion of local road length relative to total road length in the 1 km buffer. We hypothesized that higher density of local roads and higher proportion of local relative to total roads would be positively associated with higher walking, bicycling, and jogging.

In models using density of local roads as the main exposure, the density of non-local roads served as a control variable, and in models using the proportion of local relative to total roads as an exposure, total roads were used as a control, because local and non-local roads are each related to behavior and non-local roads may confound the association between local roads and PA. This is analogous to what is done in energy partitioning and nutrient density models (Willett, 1998).