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Neighborhood walking densities: A multivariate analysis in Halifax, Canada

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ABSTRACT

Neighborhood walkability is important to planners and policy makers in the public health, land use planning, and transportation fields. This research contributes to knowledge of walking behaviour by aggregating GPS-tracked walking trips as neighborhood walking densities, and investigating local characteristics affecting those densities. The study maps walking trips in urban and suburban neighborhoods of Halifax, Canada, using data from the Space-Time Activity Research (STAR) survey conducted in 2007–2008. Respondents completed a two-day time-diary, and their movements were tracked using a GPS data logger. The 1971 primary respondents recorded 5005 geo-referenced walking trips.

From mapped walking tracks, walking distances were aggregated to 87 census tracts, and expressed as walking densities (per resident, per meter of road, and per developed area). Multivariate regression was used to examine which neighborhood variables and socio-demographic controls are most useful as estimators of walking densities. Contrary to much of the walkability literature, built-environment measures of road connectivity and dwelling density were found to have little estimating power. Rather, retail lot coverage ratio was the single most useful estimator, acting as a proxy to identify traditional retail shopping streets. Office and institutional land uses were also important contributory estimators (highlighting areas of dense employment), as were measures of residents' income and age.

1. Introduction and aims

Neighborhood walkability is particularly important to urban designers, planners, policy makers, and those in the public health, environmental, and transportation fields (Saelens and Handy, 2008; Li et al., 2015). The concern for neighborhood walkability stems from desires to improve public health, reduce infrastructure costs, and reduce environmental impacts of transportation.

Health and medical researchers have promoted walking as a beneficial form of physical activity and report that even moderate amounts can have positive impacts on public health (Frank et al., 2004; Ewing et al., 2013). Mowat (2015, p. es3) argues the relationship between the built environment and health has "entered the mainstream of public health practice". Improvements in the built environment can encourage physical activity, particularly walking (Saelens et al., 2003a; Leslie et al., 2005; Cerin et al., 2006). Greater participation in active transportation (AT) would also reduce the need for costly infrastructure improvements and future transportation investments (Cervero, 1988; Gordon and Richardson, 1997; Frank, 2000). Concerns surrounding climate change and greenhouse gas emissions have encouraged urban designers, planners, and policy makers to reduce reliance on automobile travel and encourage the use of both public transit and AT (Boarnet et al., 2011).

Based on the concerns noted above, there is a considerable research focus on neighborhood characteristics that enable and encourage walking, often termed neighborhood walkability. Marshall et al. (2009, p. 1752) define walkability as "a measure of how conducive the built environment is to walking and that predicts physical activity and active transportation". Researchers suggest that neighborhood walkability can be measured by scoring several objective physical characteristics of the built environment, thereby creating an index of walkability (Saelens et al., 2003b; Leslie et al., 2007; Frank et al., 2009; Mayne et al., 2013). Walkability indices can be used to evaluate neighborhood designs and to either estimate or better understand the likelihood of physical activity of residents.

The purpose of this research is to map the location of walking activity in a medium-sized North American city, and to identify built environment characteristics associated with walking activity aggregated at the neighborhood (census tract) level. This research uniquely contributes to knowledge of walking behaviour and walkability by employing objective GPS tracking to map all walking trips, and by expressing aggregate patterns of walking as neighborhood walking densities. The focus of attention is thus on estimating and explaining where walking occurs, based on the attributes of the neighborhoods

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where it occurs. This approach contrasts with much of the literature, which typically is concerned to explain who will walk, based on their personal characteristics and the attributes of their home location. The research is particularly concerned with evaluating the utility of the highly-cited index of walkability (e.g. Frank et al., 2005; Lee and Moudon, 2006) against objective and verified walking data, and ultimately to provide insights that will lead to improved neighborhood design.

2. Theoretical and empirical background

Considerable research has focused on relationships between walking activity, health, and the built environment, typically using self-reported quantities of walking. These studies hypothesize that walking behaviours are significantly affected by the 'walkability' of neighborhoods focused on respondents' homes, thus making an implicit assumption that walking largely or exclusively occurs within such neighborhood areas. Early papers on this topic were provided by Frank and Engelke (2001), Handy et al. (2002), Moudon and Lee (2003), and Saelens et al. (2003a). Many empirical studies have been conducted, and several meta-studies are now available (Saelens and Handy, 2008; Sallis et al., 2009; Ewing and Cervero, 2010; Renalds et al., 2010; Lovasi et al., 2012; Koohsari et al., 2015).

Many studies use measures of residential density, street connectivity, and land-use mix proposed by Boarnet and Sarmiento (1998) and incorporated into a single 'Walkability Index' by Frank et al. (2005). Though easy to understand, the sub-indexes are inter-correlated, so that their effects are not simply additive. In an alternative approach, Lee and Moudon (2006) employed multiple regression to isolate the separate effects of many home-centered land-use and urban-form measures. Their approach is more statistically rigorous, but difficult to replicate or employ as an index. More recently, Ewing and Handy (2009) made an interesting attempt to measure subjective qualities of the urban street environment, using ratings from an expert panel.

A major problem with walking studies in general has been the quality and reliability of data on walking behaviours. Most studies have relied on subjective recall questionnaires, which gauge walking amounts by a small number of categories, rather than by exact number or length of walking episodes. These data are subject to both recall bias and social-desirability bias (Podsakoff et al., 2003; Van der Ploeg et al., 2010). A few walking studies have employed time diaries, which are more accurate than recall questionnaires (e.g. Forsyth et al., 2007; Frank et al., 2008, 2010; Koohsari et al., 2017), and several recent studies have employed a time-diary in combination with accelerometers and/or GPS tracking to measure distances/durations (Forsyth et al., 2007, 2008; Dewulf et al., 2012; Millward et al., 2013; Rundle et al., 2016).

Following early work by Boarnet and Sarmiento (1998) and Frank et al. (2005), the most common research approach has been to treat individuals as cases, their subjective recall of walking frequency as the dependent variable, and characteristics of the home-based neighborhood as independent variables. Personal characteristics such as age, sex, car ownership, etc. are usually included as control variables. Our study employs more objective, GPS-verified, data on the location of all walking trips, not just home-based trips. We also take a very different approach to analysis, in that our cases are neighborhood census tracts (CT's), the dependent variables are aggregate measures of all walking occurring in each CT, and the independent variables measure the built environment and socio-demographics of each CT.

3. Data and methods

3.1. The STAR survey data

This study employs data for urban and suburban districts of the medium-sized North American city of Halifax, Canada (population c. 400,000). Walking data were collected as part of the Halifax STAR Project, a joint project between Saint Mary's University and Halifax Regional Municipality, in 2007–2008. The STAR project was a unique survey that collected information from randomly-selected households regarding travel activity and time-use (Spinney and Millward, 2011). Primary respondents in each household completed 48-hour time diaries, and carried GPS data loggers (HP iPAQ) to track out-of-home movements (at three points every 2 s). The GPS data were used to verify time diaries through telephone prompted-recall interviews. Walking episodes were required to be at least 1 min in duration, and concluded by at least 1 min rest at a defined location, and/or by a change in travel mode or activity; for this reason, very short walks (e.g. to a car, bus stop, or mailbox) were not identified. Of the 1971 primary respondents, 1189 recorded at least one walk, for a total of 5005 walking episodes (trips). The mean duration of all walking episodes was 13.6 min, and the median was 6 min.

The 781,205 individual GPS points were imported into IBM SPSS Statistics version 21. We deleted points with fewer than six satellites, those with horizontal dilution of precision greater than eight, and those with zero speed from the previous point. The remaining 159,699 points were converted into continuous lines related to each unique walking event. A manual, judgement-based editing process was then performed to improve track accuracy and/or delete illogical or incomplete tracks. For example, a walking track might cross a residential housing block on a diagonal, and there may be insufficient data to accurately realign the track along the street network. In other cases the track appeared to cross lakes or inlets of the ocean, and in such cases the entire walking track was deleted. Full details of data editing and track weeding procedures are provided in Neatt et al. (2016), and analysis of respondent characteristics, trip purposes, and trip destinations are provided in Spinney et al. (2012) and Millward et al. (2013).

3.2. Dependent variables

To more objectively relate the incidence of walking to neighborhood characteristics, each walking track (or portion thereof) was associated with the particular census tract (CT) within which it was located, and an aggregate walked distance for each of the 87 CT's was calculated. Census tracts provide a good meso-scale compromise as a spatial unit, and have advantages related to data availability and their internal homogeneity. Since CT's vary considerably in area, population, and degree of development, three walking densities were developed to measure walked distance per CT in a comparable manner. These densities were:

- W/P = aggregate walked distance divided by resident population of CT
- W/R = aggregate walked distance divided by CT road length
- W/DA = aggregate walked distance divided by CT developed area (area in residential, commercial, institutional, park/recreation, office, or industrial use)

Although a strong positive correlation among the three density variables is acknowledged (see Table 1), they measure somewhat different aspects of the environment: W/P relates primarily to the demand for walking opportunities, whereas W/R is a proxy for the available supply of walking routes. W/DA relates to aspects of both supply and demand, in that developed areas contain both far more opportunities for walking than do undeveloped forests and fields, and also far more people. One should bear in mind that not all walking within a CT will be performed by residents of that neighborhood, and indeed perhaps only a small portion of walking will be by residents (for example, in downtown areas, or in areas with many retail, office, or institutional destinations). For this reason, there will not necessarily be a strong correlation between resident population and aggregate walking behaviour.