A massive geographically weighted regression model of walking-environment relationships


A B S T R A C T

Many studies aim at identifying environmental correlates of walking in order to identify specific potential levers for tackling the medical burden of physical inactivity. The links between environmental characteristics and walking behaviors are usually context specific. While local studies fail to embrace a global overview of these contexts, global studies hide the context scale patterns. In this study, we applied a geographically weighted logistic regression (GWR) on a large area (whole of France) to explore spatial variations of the relations between five environmental variables and walking for leisure and errands purposes among 40,480 French adults. This approach allowed us to adopt a global view of local patterns of relations and to highlight spatial contexts (defined through a clustering of GWR odds ratios) where combinations of correlates varied. Specifically, clustering algorithms on the GWR odds ratios led to 9 and 6 clusters for walking for leisure and errands, respectively. Some clusters were characterized by a particularly strong effect of population density, whereas others exhibited low effect of vegetation cover rate. Chi-squared tests indicated that these clusters were associated with type of urban areas (Paris, major urban poles, periurban areas, small urban poles, isolated areas) for the two types of walking. Beyond its methodological contribution - providing a method to handle large data samples into GWR analyses - this study offers key elements to practitioners and policy makers to target relevant contexts and environmental features for promoting daily walking.

1. Introduction

Walking, as one main component of daily physical activity, contributes to reduce the risk for chronic diseases, such as cardiovascular disease, diabetes, breast and colon cancers, and depression (World Health Organization, 2017) as well as increasing collective well-being and social cohesion (Zhu et al., 2014). Active mobility also helps hampering air pollution and traffic congestion (Christiansen et al., 2016; Sallis et al., 2012). According to the socioecological model, considered as a common conceptual framework for studying health-related behaviors (McLeroy et al., 1988; Richard et al., 2011; Sallis and Owen, 2015), other dimensions than individual one (i.e. socioeconomic and psychosocial dimensions) are assumed to act in concert to influence walking: the social (i.e. interpersonal) environment (e.g. Clark and Scott, 2013; Giles-Corti and Donovan, 2003), the socioeconomic environment (e.g. Riva et al., 2009), the natural environment (Aultman-Hall et al., 2009; Clark et al., 2014; Saneinejad et al., 2012) and the built environment. Many scholars therefore seek to explore active mobility determinants in order to identify potential levers that would favor a shift towards healthier and more sustainable mobility behaviors. As such, the built environment, which can be modified through planning policy, has been particularly studied.

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Usually, two types of walking are distinguished: walking for transportation (i.e. for utilitarian purposes, including errands and commuting) and walking for leisure (i.e. for recreational or exercise purposes) (Forsyth et al., 2008; Saelens and Handy, 2008). It has been shown that walking for transportation is related to higher intersection densities, land use diversity, urban design, accessibility of destinations and distance to transit (e.g. Cervero et al., 2009; Ewing and Cervero, 2010; Frank et al., 2006; Leslie et al., 2007; Patnode et al., 2010; Rodríguez et al., 2009; Saelens et al., 2003; Saelens and Handy, 2008). Aesthetics and pleasantness of the environment (i.e. green spaces, open spaces of quality, low air pollution exposure, presence of lake or waterway) seem to emerge specifically as correlates of walking for leisure (Chaix et al., 2014). The assessment of the environment is increasingly specific, due first to the boom of the GIScience in the late 1990s and early 2000s (Goodchild, 2004) and then to the geospatial big data revolution we are currently living (Kitchin, 2014; Lee and Kang, 2015). However, this search for environmental determinants still suffers from two major concerns:

(i) The issue of spatial heterogeneity: the bulk of empirical studies still ignore the consequences of spatial heterogeneity, in both statistical analyses and their interpretations. According to this principle of spatial heterogeneity, the relations between socioecological variables and walking are expected to vary by place and scale. Spatial heterogeneity, elevated to the status of a geographical principle by some authors (e.g. Anselin, 1986; Goodchild, 2004) – besides the spatial dependence Tobler’s first law (Tobler, 1970) – refers to the fact that Earth’s surface is polycentric, so that means and variances of geographic phenomena drift from one place to another. The implication of this principle ties in with what Openshaw (1983) called the modifiable areal unit problem: “the results of any study of a limited area depend explicitly on the bounds of that area: shift the bounds, and the conclusions will change” (Goodchild, 2009, p. 414). Spatial heterogeneity is therefore likely one of the main sources of the well-known inconsistencies (i.e. mixed results) among studies, besides the heterogeneity of methodological choices in assessing variables (Forsyth et al., 2006), in selecting the scale of aggregation (Clark and Scott, 2014) and in analyzing them.

(ii) The issue of interrelationships between determinants: candidate determinants are often taken individually or through interaction terms that are limited to a few pairs of variables, while they should be considered as combinations of factors, free to vary, in terms of hierarchy, by groups of individuals and/or by places.

Regarding the environmental determinants of walking, some authors tried to address either the first issue, for instance through the geographically weighted regression (GWR) modelling technique, allowing to capture spatial heterogeneity of relationships (Feuillet et al., 2015), or the second one, through multidimensional environmental constructs, multilevel modelling, structural equation modelling (SEM), or even multilevel SEM (Van Acker and Witlox, 2009). However, there seem not to have attempts that have addressed the two concerns simultaneously, that is to identify combinations of environmental correlates of walking that would differ by places. One solution might consist in performing a GWR in using multidimensional environmental constructs (e.g. principal components) as explanatory variables, but the composition of such constructs should vary by location, which is not the case when they are derived from principal component analysis. Therefore, we looked at a methodological mean allowing to delineate local spatial contexts (i.e. places) in which the combination of environmental correlates of walking would vary. In other words, we have sought at maximizing within-context homogeneity in terms of walking correlates, and thus between-context heterogeneity. Such an approach was attempted at a local scale (Feuillet et al., 2016) – in the Paris area – and the challenge of the current research was to extend the approach to a larger area – the whole country.

Based on a sample of about 40,000 French adults having reported their daily amount of walking for different journey purposes (leisure and errands), our analytical strategy followed two steps: (i) we performed a GWR modelling linking walking as regressand and social/built environmental characteristics as regressors and (ii) we carried out a classification of the GWR environmental variable slopes. The main aim of this study is to point out places of spatially varying environmental correlates of walking. Such an approach could then be used as a potential tool to optimize recommendations for local policies seeking at tackling physical inactivity through increased possibilities for walking. The second aim is methodological. We proposed novel methodologies (i) for estimating massive GWR models with parallel computation and (ii) for calibrating bandwidths through empirical exploration.

2. Building the database

In this section, we present the study design, as well as the building of our database, including both individual and environmental variables.

2.1. Study design and participants

Individual data regarding walking behaviors and other individual covariates were collected in participants of the Nutrinet-Santé study, an ongoing web-based cohort launched in France in May 2009, which focuses on relationships between nutrition and health (Hercberg et al., 2010). Volunteers aged 18 years or older (age range 18–96 years) living in France and having access to the Internet fill in self-administered web-based questionnaires at baseline and then regularly during follow-up using a dedicated, secure website. They completed a set of questionnaires assessing demographic and socio-economic characteristics, as well as a questionnaire focusing on habitual physical activity and mobility, administered from February to August 2013 (n = 55,694; 48.5% participation rate). This questionnaire was designed to assess active transport in everyday life over the past four weeks. In addition, residential addresses were obtained from all participants, geocoded to the parcel or street levels and implemented as a shapefile in a geographical information system (GIS). Among the 55,694 participants who completed the physical activity questionnaire in 2013, 15,320 (27.5%) were excluded because they reported (i) physical limitations to daily mobility (n = 1730), (ii) pregnancy (n = 730), (iii) implausible physical activity values (n = 2817), or (iv) missing data regarding covariates or residential addresses (n = 10,043). The sample used in this study finally included 40,480 respondents (mean ± SD age of 48.8 ± 14.4 years). This study was conducted according to the guidelines laid down in the Declaration of Helsinki, and all procedures were approved by the Institutional Review Board of the French Institute for Health and Medical Research (IRB Inserm number 0000388FWA00005831) and the Commission Nationale Informatique et Libertés (CNIL number 908450 and number 909216).

2.2. Estimating walking outcomes

We used a dedicated questionnaire – the Sedentary, Transportation and Activity Questionnaire (STAQ), described and validated elsewhere (Menai et al., 2015; Mensah et al., 2016) – to assess individual walking time. Subjects were asked to report separately time spent walking for errands (such as shopping, bringing children to school, visiting family or friends, going to the movies, etc.) and for leisure (i.e. recreational purposes, such as walking in a park, dog walking, etc.) during the past 4 weeks, expressed as a mean duration (hours, minutes) per day. Though not used in the current study, subjects also reported time spent walking for commuting.

Since correlates of walking have been shown to vary according to walking purposes (Cho and Rodriguez, 2015; Lee and Moudon, 2006a; Menai et al., 2015; Spinney et al., 2012), we decided to keep separate these two domains of walking, i.e. considering two regressands:
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