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Where is my neighborhood? A dynamic individual-based definition of home ranges and implementation of multiple evaluation criteria

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ABSTRACT

With the growing interest in studying characteristics of geographical context and its influence upon people, the concept of home range has been a focus of scholarly research. Home ranges are studied extensively across multiple disciplines, with literature supporting different operationalization techniques. This article argues that many of the existing approaches are not dynamic and versatile enough and do not provide reliable solutions for estimating individual home ranges. We additionally argue that many of current studies lack robust evaluation approaches. Recent evidences suggest that the usual approaches, which often exclusively rely on a single validation criterion, are not reliable and may be influenced by inferential errors. This study aims to tackle the exiting limitations in definition and operationalization of individual-based home range models and provide a more robust solution for their evaluation and comparison. Using data collected through public participation GIS we develop an applied, dynamic, and parametric model of individual home ranges. Subsequently, we propose multiple criteria comprising five validation hypotheses to evaluate model's effectiveness. We argue that application of this approach in evaluating spatial delimitation models can ameliorate the risk of biased validation resulting from inferential errors. The evaluation results indicate a substantial improvement in coverage of visited points compared to previously used static methods. Consequently, this paper draws a number of conclusions that can serve as guidelines for future research. This paper highlights the strengths and weaknesses of the proposed method and explains how it can be improved and employed in future studies investigating contextual effects on residents.

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1. Introduction

There is a growing body of research on the relationship between the built environment and different aspects of individuals' health. Many studies explore the impact of both the physical and social environment on health and highlight the methodological complexities of understanding these interactions (e.g Ali et al., 2005; Bertram & Rehdanz, 2015; Booth, Pinkston, & Poston, 2005; Kestens et al., 2012; Lavin Fueyo et al., 2016; Rydin et al., 2012). One of the main complexities in this field is the geographical definition of physical environment. Studies have used varying extents and methods to define the so-called neighborhood boundaries to measure the level of physical and environmental exposure and their potential effects on health. In this study we create an individual-specific neighborhood boundary definition which can be applied in future studies investigating the environmental exposure in home surroundings. Further, in this study we use a multi-criteria strategy to evaluate the suitability of the suggested model for environmental health research.

In recent years there have been many scholarly attempts to build an evidence base for the role of neighborhood resources in health-related behaviors to guide urban planning to tackle health inequalities (Vallée, Le Roux, Chaix, Kestens, & Chauvin, 2014). Definitions of an individual's local environment and concepts of neighborhood vary widely between these studies. Many studies focus on local administrative units, such as census tracts, as spatial delimitations (Diez Roux, 2001). Such choices are primarily based on the availability of such administrative data rather than their appropriateness concerning the spatial scale at which environmental exposures may affect individuals (Perchoux, Chaix, Cummins, & Kestens, 2013). In other words, administrative units are easy but arguably ill-suited solutions to represent the

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appropriate space to evaluate environmental effects on health, since they typically do not represent the true experienced exposure (Lee et al., 2008; Perchoux et al., 2013).

In order to overcome limitations associated with application of administrative and district boundaries as the spatial delimitation for health related studies, many scholars have suggested the use of individual-based neighborhood definitions (Wong & Shaw, 2011). The most common approach to operationalize these ego-centered boundaries is to draw buffers around each individual's place of residence. Different types of buffers are used such as circular or elliptic zones, and road network buffers (Oliver, Schuurman, & Hall, 2007). Various distances are used in different studies, but authors generally use a threshold distance that is easily walkable from home location. The distances used vary from as small as 400 m (Jago, Baranowski, Zakeri, & Harris, 2005), 500 m (Kytta, Broberg, Haybatollahi, & Schmidt-Thome, 2015; Markevych et al., 2016), through to as large as 8.05 km (Gordon-Larsen, Nelson, Page, & Popkin, 2006).

One of the main problems with this approach is that the distances employed are rather arbitrary and there is often limited empirical data to support the choice of buffer size. Furthermore, as Kytta et al. (2015) demonstrate, the buffers are not always inclusive, meaning that in many cases individuals are exposed to vast areas which do not fall into these distances. Moreover, use of these static buffers is based on an isotropic assumption which contradicts the commonly oriented nature of neighborhoods (Chaix, Merlo, Evans, Leal, & Havard, 2009). Another major problem with use of buffers is that they ignore the fact that areas are not equivalently accessible because of urban and natural structures (Lee et al., 2008).

Although using buffer takes the traditionally rigid neighborhood definitions to an individual level, a limitation persists, as the defined neighborhoods are individual-centered, but not individual-specific. In these approaches, the spatial extent of neighborhood is systematically defined in a uniform way for all individuals. Nevertheless, social sciences have long recognized that the scale of one's experienced or perceived neighborhood is person-specific and cannot be generalized (Chaix et al., 2009). A person's neighborhood may be shaped by his or her specific socio-demographic characteristics such as age and length of residence (Guest & Lee, 1984). Thus, these static approaches fail to account for unique ways inhabitants experience their neighborhoods (Vallée et al., 2014).

To address this limitation researchers have proposed and implemented various methods to specify neighborhoods for each individual. The most common approach is to use GPS data to map the participants' mobility. Following the acquisition of the geographical data, the neighborhood is specifically modeled for each participant using methods such as minimum convex polygon (Buliung & Kanaroglou, 2006), kernel density estimation (Bithell, 1990; Chainey, Tompson, & Uhlig, 2008), and standard deviational ellipses (Arcury et al., 2005; Schönfelder & Axhausen, 2002b). Although these approaches take promising steps toward definition of individual specific neighborhood boundaries, the rigidity originating from their purely mathematical nature contradicts the flexile characteristic of such spaces. Therefore, the need for more versatile approaches persists.

Furthermore, the way neighborhood definitions are operationalized is not the only limitation of studies to this point. Another fundamental source of problem is the lack of robust ways to evaluate neighborhood definitions. In most cases the evaluation is done on the basis of the strength of association between environmental factors and a dependent variable such as health (Chaix et al., 2009). A complementary strategy is to rely on model fit indicators to compare models with neighborhood effects assessed with different spatial delimitations (Chaix et al., 2006). These methods are based on the assumption that an improper definition of exposure area boundaries can only result in dilution of the effect and therefore the underestimation of the association (Chaix, 2009). However, Spielman and Yoo (2009) challenge the use of these approaches by arguing that their use can be misleading in discovering proper area delimitation. Similarly, Kwan (2012a, 2012b) argues that any observed association can be a result of inferential error and therefore cannot necessarily indicate the spatial scale's suitability. In other words, an uncertain geographic context can result in overestimation as well as underestimation and thus cannot exclusively be considered as an evaluation criterion.

Motivated by limitations present in both definition and evaluation of spatial delimitation methods in environmental health research, this study aims to present a new neighborhood defining tool as well as a new, more robust, evaluation approach which can ameliorate the existing uncertainties in definition of neighborhoods. In this study, we use public participation GIS (PPGIS) to collect geocoded data on participants' mobility and frequently visited points. PPGIS data was collected in Helsinki metropolitan area, Finland, in autumn 2009.

Past research in geography, activity, and travel has showed that people move around in space and time in order to undertake their daily activities (Burnett & Hanson, 1982; Hanson & Hanson, 1981; Kwan, 1999, 2000). Similarly, the human activity space can be defined as a set of geographically distributed locations which are physically contacted by individuals (Reynolds & Horton, 1971). Therefore, in this study we use frequently visited points, in addition to home locations, in order to specify neighborhood boundaries. Furthermore, people often travel beyond administrative boundaries and official area delimitations and come under influence of various neighborhood contexts (Matthews, 2011; Sampson, Morenoff, & Gannon-Rowley, 2002). Hence, neighborhoods defined in this study are individual-specific and vary in shape and size regardless of the existing official borders.

The modeling process was automated as a tool using Python programming language and ESRI Arcpy package. The tool creates individual-specific neighborhood boundaries, represented as a polygon, for each person. In order to evaluate the model we defined multiple criteria consisting of five intuitive hypotheses concerning age, health, and population density. By using multiple criteria, the risk of any misevaluation caused by relying on a single criterion is potentially ameliorated.

It is noteworthy that a wide range of terms is used in literature to address different aspects of neighborhood delimitations. These terms include, but are not limited to, activity space, home range, home zone, neighborhood, and neighborhood boundary. In order to avoid any confusion caused by multiplicity of terms, from this point on we use the term “home range” and we define it as: a sub-space of activity territory encompassing frequently visited points, which are easily accessible from inhabitant's home. Home range as a concept was first introduced by Burt in the field of zoology and was defined as the area within which an animal does its normal activities (Burt, 1943). The most common way of measuring home range is the minimum convex polygon (MCP), also known as convex hull in mathematics, which is the smallest convex polygon containing a set of points (Moorcroft & Lewis, 2006; Schoener, 1981). The use of MCPs was later introduced to social sciences to measure the relationships between urban morphology and human activities (Buliung & Kanaroglou, 2006).

In this paper, we will present the model specifications, operationalization process, and evaluation results. We will conclude this paper by reflecting on our method and discussing the significance our findings to future research.

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