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Conceptualizing the healthscape: Contributions of time geography, location technologies and spatial ecology to place and health research☆

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ABSTRACT

Geomatics and related technologies allow for the application of integrated approaches to the analysis of individual spatial and temporal activities in the context of place and health research. The ability to track individuals as they make decisions and negotiate space may provide a fundamental advance. This paper introduces the need to move beyond conventional place-based perspectives in health research, and invokes the theoretical contributions of time geography and spatial ecology as opportunities to integrate human agency into contextual models of health. Issues around the geographical representation of place are reviewed, and the concept of the healthscape is introduced as an approach to operationalizing context as expressed by the spatial and temporal activities of individuals. We also discuss how these concepts have the potential to influence and contribute to empirical place and health research.

Main text

Introduction

The mutli-disciplinary influences in the study of place and health has led to a variety of approaches and considerable debate over the conceptualization and measurement of contextual effects (Dear & Wolch, 1987; Ellaway, Macintyre, & Kearns, 2001; Kawachi & Berkman, 2003; Pickett & Pearl, 2001). A chief value of place is that it provides the conceptual and analytic platform for studying population health status and health inequalities (Bernard et al., 2007; Bottero & Prandy, 2003; Curtis & Jones, 1998; Graham, 2000). A fuller understanding of how place affects health and healthy behaviours requires information about how the structuring of social processes among people is associated with the structuring of contexts they live in (Jones & Moon, 1993; Kearns & Joseph, 1993; Macintyre, Maciver, & Sooman, 1993).

Characteristics of context are influential upon health and there is good empirical evidence showing that place affects health directly, and indirectly, through influence on individual activities and health-related behaviours (Boyle & Willms, 1999; CIHI, 2003; Diez Roux, 2002; Frolich, Potvin, Chabot, & Corin, 2001; Macintyre, Ellaway, & Cummins, 2002; Popay et al., 2003; Sampson, 2003). People have varying degrees of autonomy when making choices about where to live and work, who they socialize with, as well as the actions they take to minimize health risks. However, the freedom to make these choices is often illusory because we seldom account for the features of context and their role in the development of human well being. For example, walking as an activity to promote a healthy lifestyle is less attractive in suburban or semi-rural neighbourhoods that are often lacking sidewalks or trails. Often these health promoting or harming features of context go unnoticed. Yet, it is often the interplay between people and place that ultimately influences health and healthy behaviours (McDowell, Spasoff, & Kristjansson, 2004; Sampson, Morenoff, & Gannon-Rowley, 2002; Skjaeveland & Garling, 1997).

Advancing research on context and health relationships requires a reorientation of our ideas about place. In conventional population health research, geography is ostensibly the spatial container used to differentiate people for the purpose of developing explanations of health and health-related behaviours. The challenge posed by Eyles (1993), and more recently Cummins, Curtis, Diez-Roux, and Macintyre (2007), is to embrace a relational perspective in which context is implicated in human activity. In other words, population health research should be explicitly engaging the spatiality of social life within research on place-based explanations of health. These

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explanations should recognize that people *and* places make a difference (Macintyre et al., 2002).

Advances towards the discovery of contextual features relevant to health have been made in several areas (Flowerdrew, Manley, & Sabel, 2008; Frohlich, Potvin, Chabot, & Corin, 2002; Hillemeier, Lynch, Harper, & Casper, 2003; Mujahid, Diez Roux, Morenoff, & Raghunathan, 2007). Despite these advances, place boundaries are usually rigid and disregard temporal processes across geographic space. Many alternatives to conventional spatial structures fall short of integrating the dynamic character of social life, or the potential for influence from places beyond the 'boundaries' of everyday existence (Sampson, 2003; Wellman & Berkowitz, 1997). This conventional thinking may be less valid in a reality where people and activities are becoming disconnected from locations, and where interactions among people in multiple places are important. Advancing our understanding of contextual influences on health will require research that transcends emphasis on the structural arrangement of context to a perspective concerned with how people, and the activities they perform, are situated in different contexts at discrete times.

This paper contributes to the conceptual and methodological knowledge of integrating the space-time dynamics of human enterprise into place and health research. A primary focus is on the benefits that accrue from better knowledge of the dynamics of human movement, and how these movements lead to health and place research that acknowledges interactions among people with different health states in multiple contexts. The aim is to supplement conventional ideas of place by initiating discussion on issues of spatial bounding and the role of time geography in place and health, and to review advances in data collection and analysis techniques so that movement and mobility are considered in empirical analyses.

Issues of space bounding in place and health research

Place is usually represented physically in terms of notional geographic boundaries, as implied by 'community', 'neighbourhood', 'meaningful areas', or by fixed administrative areas (census tracts, wards, zones, or other boundaries). Administrative boundaries are usually developed by government agencies for purposes other than health research, or developed by health researchers using statistical procedures. Such representations of population distribution and context may work well for a traditionally low mobility population living in an area with stable living conditions. In reality, however, neither the people living in an area, nor its attributes, are likely to be static. Data collected by government agencies for the development of public policy are usually collected without consideration of spatial or dynamic processes (Hayes, 2003). Hence, demographic and census-based variables commonly used in place-based health research form crude markers for the full range of conditions that could buffer or enhance the effects of place on health (Bronfenbrenner, 1977; CIHI, 2003; Gatrell, 2002).

Conventional approaches to delineating boundaries effectively negate the concept of dynamic populations. Attribution of one address or residential boundary as an identifier of the primary place in which health behaviours or outcomes develop may not provide an accurate view of the impact of place. While it could be argued that residential locations or neighbourhoods are distinguished by a stronger sense of attachment to place, most people experience a multiplicity of places and locations. These include work, places to socialize (Allison et al., 1999), and 'third places' such as cafés, post offices, and public parks, where people gather and interact. Third places are the necessary ingredients for developing strong community ties and civic engagement (Oldenburg, 2000).

Efforts to more accurately render the boundaries of place will inevitably be more meaningful to the population(s) under study and to the development of place-based health policy. Several studies have used local knowledge (Bernard et al., 2007; Coulton, Korbin, Chan, & Su, 2001; Ellaway et al., 2001; Frohlich et al., 2002), community mapping exercises (Coulton et al., 2001; Guest & Lee, 1984; Haney & Knowles, 1978; Lee & Campbell, 1997), or zone design techniques to explore the effects of boundary alterations on research results (Cockings & Martin, 2005; Flowerdrew et al., 2008; Haynes, Daras, Reading, & Jones, 2007; Martin, 1998).

Although the ideal level of spatial aggregation for best approximating place remains elusive, researchers should be cautious of results from studies that allocate people to a single context. A recent study on the association between accessibility to green spaces and physical activity allocated the percentage of green space available to an individual within a 1 km or 3 km radius around their home postal code (Maas, Verheij, Spreeuwenberg, & Groenewegen, 2008). The approach assumes that human activities, as well as the features of place producing health variations among the population of interest, are positioned within a predetermined geographic boundary. Inevitably, this assumption will lead to the misclassification of context to health outcomes (Diez Roux, 2001), or will severely underestimate the variation in context associated with the heath outcome(s) of interest. There is much uncertainty about appropriate geographic boundaries for place (Diez Roux, 2004; Krieger, 2003; Krieger et al., 2002). It seems reasonable to hypothesize that the majority of people do not spend all, or even most of their time in any one pre-defined geographically bounded area. An imperative for place and health research is to consider empirically the diversity of places that influence health, including those places geographically distant in space and time. Place-based health research would benefit from both a greater knowledge of the patterns of movements of people, and insight into the heterogeneity of context associated with these movements within the population of interest. Capturing interactions with neighbours, such as borrowing tools or a cup of sugar, would occupy a smaller spatial scale than the walking environment. The intractable task at hand is to determine the most appropriate scale at which places influence a specific health behaviour or outcome; or, ideally, to allow for flexible scales suited to the space-time patterns of every individual.

The influence of place also changes over the lifecourse. Children are more likely to develop stronger attachments to locations much closer to their place of residence: longitudinal analyses show that the quality of places early in the lifecourse has a significant effect on health outcomes later in life (Curtis, Southall, Congdon, & Dodgeon, 2004). As children develop into adolescence, social and physical bonds to places near their residence are diminished due to an increase in relationships outside home neighbourhoods, increased mobility, and independence (Schiavo, 1988). This trend of increasing mobility and spatial extent carries into adulthood until the later stages of the lifecourse when there is a return to stronger attachments with specific places (Fig. 1).

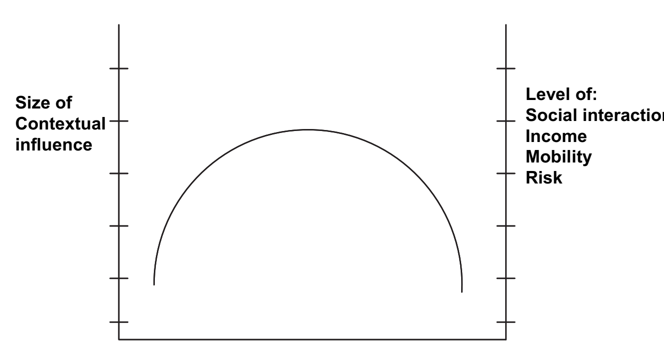

Fig. 1. Hypothetical influence of context over the lifecourse.

Context as space-time ecology

The logic of time geography is oriented towards contextual research where physical, mental and socio-cultural aspects and their mutual interrelationships are part of the analysis of human agency (Hägerstrand, 1970, 1985). All human activities have spatial and temporal dimensions: activities occur at particular places for limited durations. The approach evolved from Hägerstrand's observations about the need to reveal the context of human action, where time and space are the principal variables for social analysis. Forms of interaction – social and otherwise – are recognized as spatial processes (Ellegard, Hagerstrand, & Lenntorp, 1977; Pred, 1977).

Time geography rests on the notion that the locations and movements of individuals can be followed and visualized as continuous paths in spatial and temporal dimensions. Unlike conventional place-based health research, which is usually limited to analyses based on residential location, a time geographical approach allows for the examination of place as the spatial, temporal and contextual terrains that influence individual health status; these terrains are not necessarily geographically proximal to one's residential neighbourhood. The challenge, at least from a population health perspective, is to comprehend the dialectic between the individual and the society, or the interplay between individual behaviour, the interactions between people, and the more structured relationships occurring between people and their institutions (Miller, 2001; Parkes & Thrift, 1980; Pred, 1981).

In time geography, time and space are joined in a space-time context where events and process unfold in sequences of situations. This quite simple conceptualization can be represented by a simple data structure to describe human movement and activities, and consists of a coordinate vector (x, y, t, a) which defines the spatial location (x, y) of an activity (a) at a specific time (t). The space-time 'path' describes a person's movement from one location to another in two-dimensional space, with time (z) represented by the z-axis orthogonal to place (Fig. 2). The path is vertical when an individual is stationary at a specific location (x, y) and becomes more horizontal when moving through space. The slope of the path is determined by the movement velocity – a result of travel mode constraints. Paths can converge and diverge. Note, however, that convergence could also occur between people and environmental hazards, pathogens, or any such characteristics of places, and that paths may vary in duration from a few minutes to entire lifetimes (Kwan, 2002).

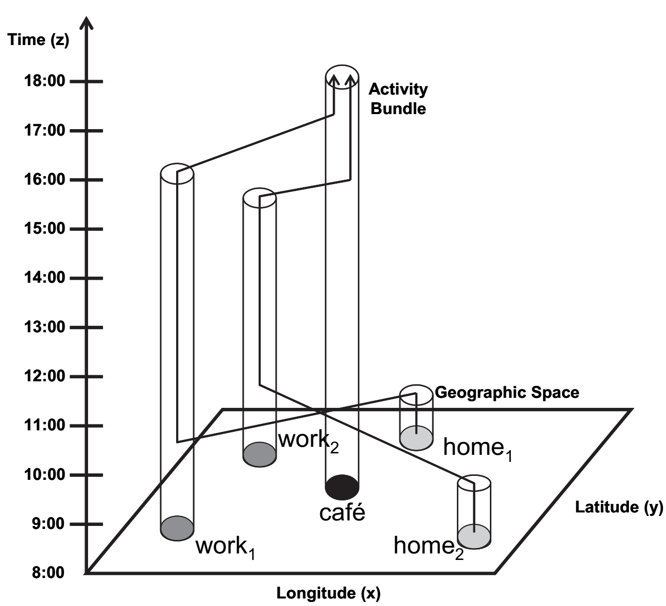

Fig. 2. Space-time paths of two individuals. Time spent at café represents the 'convergence' of two paths and is also called an activity bundle. The sharing of moments in space-time provides insight into the spatiality of social interaction.

Variations in space-time pathways and activities are subject to a taxonomy of dimensions related to human agency (Hägerstrand, 1970; Pred, 1977). Three dimensions—capabilities, convergence and authority—are crucial components shaping the activities of individuals, and give emphasis to the significance of power relationships in the structuring of context. The capability of individuals to pursue any activity is influenced by physical and social conditions, genetic predisposition or the latitude to acquire and control resources for personal gain. These activities may coincide, or converge in space and time with other people, tools or resources, leading to variations in the levels of social interaction of support. However, human agency can be restricted territorially by forces asserting influence and control. Territoriality is an attempt by an individual or group to influence, or control people, processes, and relationships, by delimiting and asserting control over a geographic area (Sack, 1986). For example, local governments can modify zoning rules to allow more or less healthy forms of development; they may also dictate public transportation timetables making it more or less difficult for some individuals to travel efficiently.

The nexus of these dimensions, when linked to information about the geographic boundaries of human activity, leads to a structuring of context and invariably the processes leading to the social structuring of society (Parkes & Thrift, 1980; Pred, 1983). An agency-based perspective places a greater emphasis on the significance of power relationships as a determinant of spatial bounding. Places are constructed to some degree by the dynamic social relations and power struggles among groups in society (Delaney & Leitner, 1997; Massey, 1993; Pred, 1983). Ultimately, place is a form of healthscape or the product of several geographic properties that include the attributes of context, the spatial and temporal relationships between people and their surroundings, as well as the characteristics of human behaviour, relationships and the activities they perform.

Positioning people and context in space and time

The potential to expand conventional place-based health research to include space-time-activity information requires a re-examination of existing data collection procedures as well as the development of new tactics for the collection and analysis of space-time-activity data. Gathering information on the location and timing of human activities is notoriously difficult: space-time-activity data are usually expensive to obtain and prone to error (Golledge & Stimson, 1997). In addition, researchers must keep in mind issues associated with data confidentiality as well as the potential to introduce bias from participant non-compliance.

Data on the temporal sequencing of human activities are usually derived from time-use studies. These usually consist of diary-based instruments designed to understand time-use and activity patterns at a diurnal scale but rarely provide location information (Harvey & Pentland, 1999; Janelle, Klinkenberg, & Goodchild, 1998). Large scale time-activity studies can provide fairly detailed accounts of daily activities as well as supplementary sociodemographic information and data on household and mobility characteristics. For example, an activity study in Canada collected data that were used for international activity pattern comparisons and in the development of air pollution exposure assessment models (Leech, Nelson, Burnett, Aaron, & Raizenne, 2002; Leech, Wilby, McMullen, & Laporte, 1997).

To overcome some of the difficulties inherent in the collection of georeferenced time-activity information, researchers can modify survey methods or adopt new technologies to facilitate the collection of space-time-activity data. Redesigned survey methods could include the use of web-based survey techniques which allow the respondent to link individual activities to locations on maps. Users can also add information about travel modes and other contextual information relevant to the study, such as responses to questions about health status. Another option is to access auxiliary databases that contain space-time-activity information that were not designed for the purposes of conducting place and health research. For example, it is possible to obtain cellular phone records from service providers for the purposes of research provided that individual-level information on the subscriber is not published. Several studies have used data from mobile networks to map and explore the structure of social and communication networks, as well as to determine respondent locations with a relatively high degree (15–30 m) of accuracy in urban locations (LaMarca et al., 2005; Onnela et al., 2007).

Location-aware technologies (LAT) consist of devices that can report or log their geographic location in near-real time. These technologies have the potential to greatly reduce the cost and improve the accuracy of collecting space-time-activity information (Murakami & Wagner, 1999; Stopher, FitzGerald, & Zhang, 2006). There are several georeferencing methods employed by LATs including radiolocation, radiofrequency identification, and geo-sensor technologies. Perhaps the most widely used and most accurate approach is the use of global positioning systems (GPS). To date GPS tracking has been concentrated largely in the study of travel patterns, particularly in conjunction with household travel surveys (Wolf, Schönfelder, Samaga, & Axhausen, 2004), and studies of species range in wildlife and biological research (Hulbert & French, 2001; Phillips, Elvey, & Abercrombie, 1998; Rodgers, 2001). More recently innovations in GPS tracking and logging technologies have resulted in the development of wearable or portable devices (Rainham, Krewski, McDowell, Sawada, & Liekens, 2008). Wearable GPS uses differences in timing data from a constellation of satellites to determine an individual's location. This information can be logged passively or sent in real-time using cell phone networks to a remote server for further analysis, and allows researchers to map an individual's space-time path through multiple contexts. These contexts may include path anchors such as home or workplace, or may include resources in areas adjacent to these areas that differ in terms of their ability to promote or impair health.

Although in its infancy, the use of GPS technology for human tracking presents an enormous opportunity for improving our understanding of how context as represented by the space-time activities of individuals can influence health and well being. Recent applications of GPS technology for health research have been concentrated on physical activity assessments and human exposure studies. For example, lightweight GPS receivers were used to assess physical activity as measured by the velocity of walking and running (Schutz & Chambaz, 1997), and to geographically contextualize accelerometry data or the locations where physical activity occurs (Rodriguez, Brown, & Troped, 2005). Wearable GPS have also been used to track individual exposure to chemicals in community-based exposure assessment research (Elgethun, Fenske, Yost, & Palcisko, 2003). The utility of wearable GPS receivers is enhanced when linked to additional sensors that can monitor physiology, or specific exposures such as air pollution (Milton & Steed, 2007; Pandian et al., 2008).

There are clearly important ethical and privacy issues associated with the tracking and recording of a person's activities in space and time, and people willing to wear such devices may not be representative of the general population. Wearable GPS and other LATs can provide fairly accurate point level time and location data, thus enabling, through visualization and mapping techniques, an estimate of an individual's residential, work, or other locations that form aspects of daily or weekly routines. Several obfuscation techniques are now available to protect data confidentiality, including geographic masking, software agent-based data confidentiality, and techniques for mobile objects (Armstrong, Rushton, & Zimmerman, 1999; Armstrong & Ruggles, 2005; Boulos, Cai, Padget, & Rushton, 2006; Duckham & Kulik, 2005). In reality, concerns about the negative use of locational data must be balanced against the potential for societal benefit accruing from an improved understanding of how place influences an individual's space-time path, the activities they undertake, and ultimately their well being.

Finally, developments in wearable positioning and geographic information technologies provide an opportunity to quantitatively measure an individual's exposure to multiple contexts and to compare these measures against exposures derived from conventional contextual boundaries. The most useful locational attributes are points with precise location (latitude and longitude) coordinates measured from GPS or from geocoding. Building on John Snow's dot mapping investigation of mortality from cholera in 1854, the analysis of point patterns comprises a significant portion of the methodological tools used in ecology, geography, and spatial epidemiology (Gaston, 2003; Gatrell, Bailey, Diggle, & Rowlingson, 1996; Goodchild & Janelle, 2004). Using point pattern analysis, it is possible to delineate the spatial extent of an individual's range (boundary), as well as the intensity of activity among locations within a person's boundary. Additional metrics such as fractal analysis and Markov chain models may also be employed to evaluate movement patterns and to account for decision-making processes about how people negotiate their way through multiple contexts (Hung, Venkatesh, & West, 2001). These characteristics of an individual's space-time path can be extended over time to detect changes in geographic range and intensity through the lifecourse. In addition, the assessment of space-time paths can be performed for much larger population samples, thus allowing for measurement of group-level activity patterns in space-time. For example, it may be of interest to ask whether the geographic incidence of social activities among individuals with low income demonstrates a tendency towards clustering in a specific location. Kwan and Lee (2004) have demonstrated that the space-time density of non-employment activity patterns of men are more spatially distributed than those for women.

Analysis of space-time data

The collection of space-time-activity data leads to the creation of very large datasets and presents difficulties for analysis. For example, GPS tracking of an individual at 1-s intervals can produce more than half a million track points in a week; each track point is recorded as a single observation with latitude, longitude, time, date, velocity, and measures of accuracy (Fig. 3). Fig. 3 illustrates the potential for misclassifying the influences of context to an individual when objective information on the spatio-temporal properties of their activities is known. While it is relatively straightforward to import and visualize GPS data in most standard geographic information system software, it is extremely difficult to conduct meaningful data analysis using standard geographic and statistical routines. Standard routines are usually unable to efficiently display and run location and attribute queries of spatio-temporal data unless there is substantial reduction of data space. This issue is compounded when space-time data are linked to activities and other individual attributes such as health determinants derived from questionnaires. The emergence of new

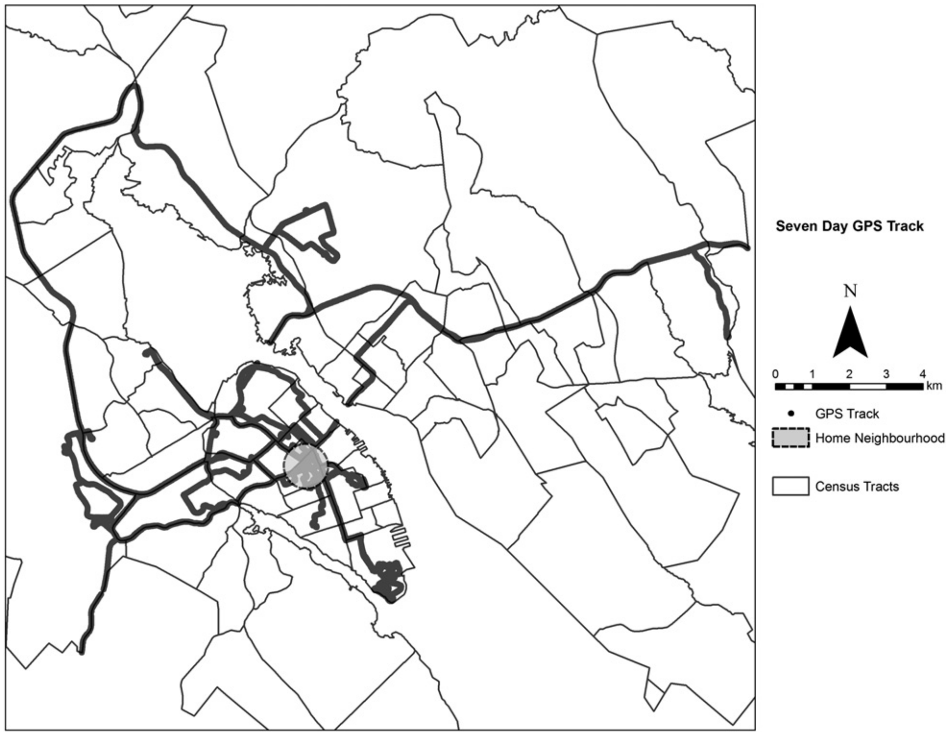

Fig. 3. Analysis of point patterns from an individual's seven-day GPS log. Data overlayed onto census tract boundaries for comparison.

quantitative and computational techniques for exploring space-time-activity information will benefit place and health research because of the ability to measure individual 'exposure' to multiple contexts.

Although no integrated methods yet exist, several approaches have been developed to explore and analyze space-time-activity data. These approaches can be categorized into three areas: visualization and related analytics, multidimensional time-activity sequencing methods, and pattern morphology metrics. Interactive and dynamic visual representations are very useful for understanding spatial and spatio-temporal data, as well as underlying phenomena. Kwan and others (Kwan, 2000; Kwan & Lee, 2004; Kwan & Weber, 2003) have used GIS to construct three-dimensional space-time aquaria to visualize human activity density patterns. In the space-time aquarium, the vertical axis represents the time of day (or the passing of time at a location) and the horizontal plane (x, y) represents the spatial extent of the study area or space-time pathways. With this type of geovisualization, it is possible to identify the contexts relevant to an individual (or group), and to investigate how the space-time pathways of individuals from different groups (gender, social, cultural) may then be contrasted. The spatial relationships of one to another, such as collocation in time and space, could then be linked to health and/or contextual data. Analyses of dynamic collective behaviour have extended more common exploratory methods of spatial and temporal data to describe both individual movement behaviours as well as momentary (temporal) collective movement behaviours (Andrienko & Andrienko, 2007). These visualization approaches identify the possible patterns in human movement data (space-time pathways) using mathematical functions and relate them to properties of space and time, properties and activities of individuals, and relevant external phenomena.

Point pattern analysis encompasses a set of methods to identify and measure spatial processes from point data (Arcury et al., 2005; Galton & Duckham, 2006). Points generated from GPS are inputs to point pattern analysis. These data can also be categorized according to time, activity, or, in the case of an epidemiological study, an exposure or health-event of interest. A number of approaches have been developed to analyze point-based location data. Fig. 4 shows the application of three common methods to seven days of GPS data. These methods include: (1) activity space (standard deviational ellipse), (2) home range (minimum convex polygon), and (3) kernel estimation (intensity) methods.

(1) *Activity space*: The human activity space is a set of geographically distributed locations physically contacted by individuals over a specified time period (Horton & Reynolds, 1971). Activity spaces can be represented by a variety of measures, although the most popular is the standard deviational ellipse (SDE). SDEs capture the spatial distribution of an individual's space-time pattern around a mean center and an ellipse at one or more standard deviations from the center. Variation in the x- and y-coordinate values may be used to generate an ellipse with major and minor axes reflecting the directional variation of the point pattern (de Smith, Goodchild, & Longley, 2007). SDEs have been used to represent routine activity spaces (Arcury et al., 2005) to assess healthcare accessibility, and to examine routine travel behaviours in urban environments (Schönfelder & Axhausen, 2004). For example, the shape of an SDE would be much narrower for an individual who regularly commutes longer distances to work than for an individual who lives closer to work or other amenities.
(2) *Home range*: The home range of any animal represents the area within which an animal carries out its normal activities. The concept was introduced as a measure of geographic activity in spatial ecology studies. The most popular measure is the minimum convex polygon (MCP) which represents the smallest convex polygon containing a set of point events (Moorcroft & Lewis, 2006). The MCP polygon has been used to examine the relationships between urban morphology and human

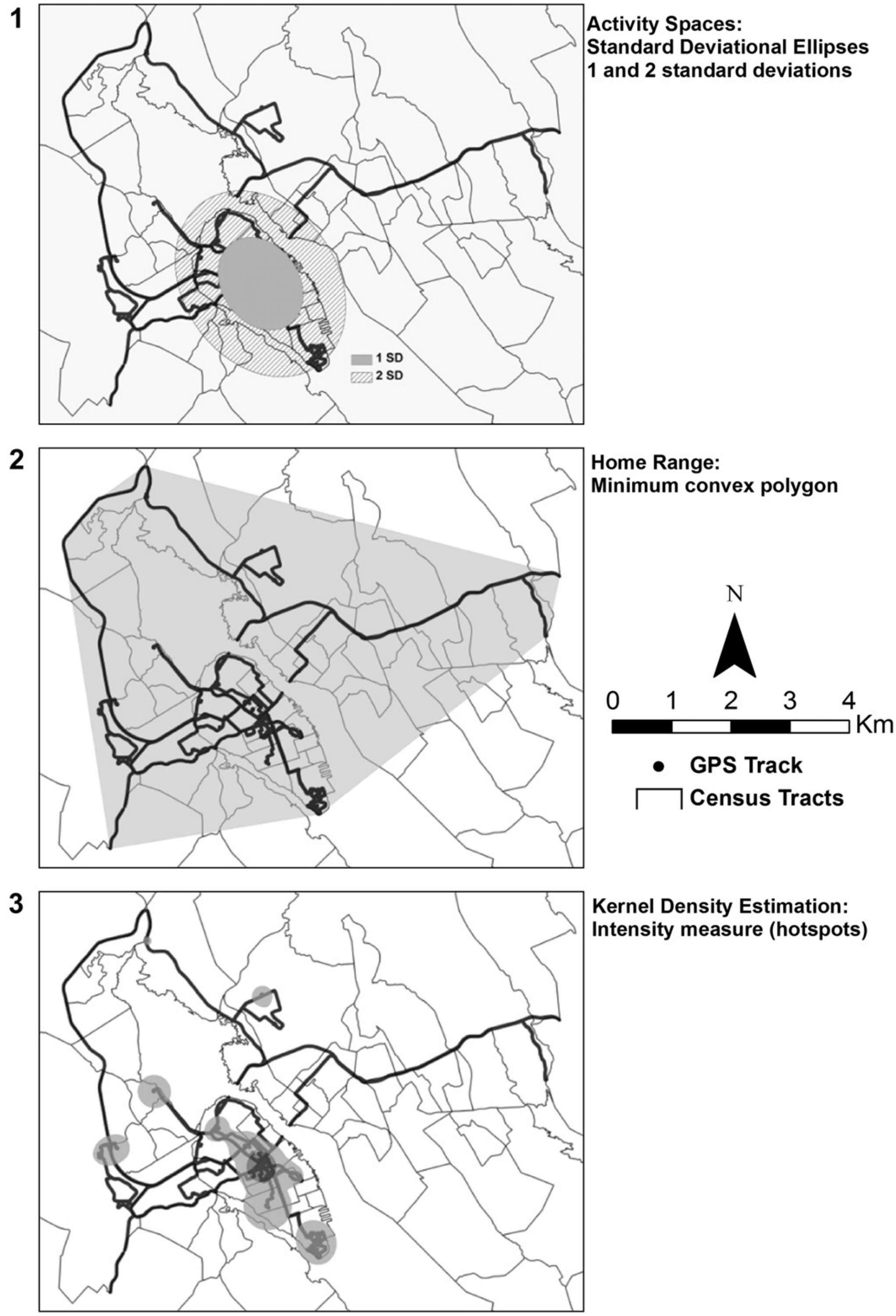

Fig. 4. Analyzing point patterns from an individual's seven-day GPS data record: (1) Activity Space; (2) Home Range; (3) Kernel Estimation. All data overlayed onto census tract boundaries for comparison.

activities, as well as the spatio-temporal nature of these activities (Buliung & Kanaroglou, 2006). MCPs are straightforward to construct and are unaffected by spatial or temporal trends within the home range boundary. While the MCP can help to identify the contexts important to health, it does not provide any information about exposure, or the intensity (using time as a proxy for exposure) to which some contexts are more or less relevant to health.

(3) *Kernel estimation*: Activities recorded over space and time can be used to develop representations of spatial utilisation or intensity as an indication of the sub-areas within the home range that are used more often. KDE is widely used in many applications including crime hot spot analysis (Chainey, Tompson, & Uhlig, 2008), and health research (Bithell, 2006). While home and work locations would figure prominently, the advantage of KDE is the ability to identify additional contexts of

particular importance or meaning. That is, there may be several different locations of regions that are not necessarily connected, each representing a variety of contexts relevant to health. For example, an individual may live in an area east of a river, work in an area west of a river and routinely visit a pub in another area. This type of information would be overlooked if conventional approaches using census geography were adopted to explore context and health relationships. A major drawback of this approach is the generation of misleading intensity surfaces since human movements usually occur in network space, rather than purely Euclidean space (Downs & Horner, 2007).

With individual space-time path and activity information in hand, researchers can draw from additional measures of movement and mobility from landscape and wildlife ecology and geography disciplines, including: metrics of paths between places, mechanistic home range analyses, graph and network theories, and measures (area, edge, elevation, landscape class, distance) from landscape ecology (Giles & Trani, 1999; Moorcroft & Lewis, 2006; Turchin, 1998; Urban & Keitt, 2001). Researchers should be open to the idea that the contexts relevant to health may not be conveniently found in one area, but may actually encompass multiple areas. Spatial boundaries derived from accurate space-time path information also enable researchers to examine the potential for misclassification when using readily available administrative spatial units.

Conclusion: a path forward for place and health research

Conventional research interests and analyses in place and health research are limited by theories and approaches that ascribe a narrowly-defined representation of context to variations in health and their determinants. This paper provides an alternative perspective, based on the concept of time geography, which might offer a more dynamic and objective understanding of how place affects population health. The development of technologies and methods represents a promising step forward for empirical place and health research. The advantage of time geographical approaches is that, while reasonably accurate individual-level space-time-activity data are required, current limited descriptors of place can be expanded to provide a more rich and meaningful insight of how place affects population health.

Currently, the potential application of time geography to place and health research is far from being realized. There are very good reasons why time geographical approaches should be integrated into place-based health research, in a manner similar to the inclusion of a lifecourse perspective into mainstream epidemiology. First, conventional place and health studies need to move beyond conventional notions of place which are characterized by notions of health and context that are static in time and space. One of the most appealing features of time geography is that it is a heuristic approach for chronicling an individual's movement through multiple places and contexts over different time periods. Ultimately, a more comprehensive understanding of the multiplicity of place will lead to the development of healthscapes. This in turn will provide improved measures of exposure which can be used to understand which contexts are most relevant to health, in terms of location and duration, as well as how an individual's personal characteristics mediate place and health relationships. Data derived from mobile technologies indicate that individuals are not limited to a single context, and that their activities vary in time and space (Kwan, 2002; Miller, 2007; Phillips, Hall, Esmen, Lynch, & Johnson, 2001; Rodriguez et al., 2005). With very little information, it is possible to construct a space-time path of loosely-defined activity locations and then explore the structure of the pattern by considering the connections individuals create among these locations and with other individuals. As more information is collected, it can be used to assess whether space-time patterns vary according to health or demographic characteristics of the population under study.

Second, methods and technologies for time geographical research are currently available, and should be exploited more fully in empirical research efforts. Although it may not be feasible to record the space-time pathways of a large sample required for national or international level research, many place and health studies focus on individual cities and neighbourhoods where time geographical approaches could be applied. By focusing on specific exposures or health outcomes, researchers can explore the scale at which processes related to context operate, and use this information to improve intervention planning. Time geographic methods are most powerful when linked to additional information about exposures and physiological measures. For example, the use of global positioning systems with personal air monitoring technologies has not only improved estimation of individual exposure to harmful substances, but has provided insights into how different contexts are associated with changes to health risk (Elgethun et al., 2003; Milton & Steed, 2007; Schutz & Chambaz, 1997).

Despite the usefulness of time geographic methods and perspectives for the development of a healthscapes approach, there are several limitations and challenges. To date, methods to analyze time geographic data have been largely limited to techniques in visualization and exploratory analysis. Spatial integration of time geographic data with additional data on local environments will provide powerful insights into the complex relationships between context and health. However, there remains a major challenge to understand how these relationships hold under conditions where individuals are interacting with other people, and for group processes. All of the methods presented in this study rely somewhat on a process of generalization to translate real-world spatial and temporal processes into defined polygons. A challenge for researchers who wish to undertake a context and health research using time geographic approaches is to develop analytical methods that deal with objectively measured space-time information without undue spatial or temporal discretization.

Adopting a time geographical approach does not mean displacement of conventional or alternative approaches to the study of place and health. Certainly, conventional empirical approaches have been valuable in emphasizing the role of place as a determinant of population health. We suggest time geography as a theoretically and empirically powerful adjunct to conventional approaches. The relative simplicity and flexibility of time geographical and related theoretical approaches to place and health can improve our comprehension of the healthscape: the spatial and temporal interdependencies that exist between people and places. Future place and health research must thus develop conceptual approaches and analytical tools that explore the geometric, dynamic, and semantic properties of places and the people who inhabit them.

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