Health and Place 58 (2019) 102072

Contents lists available at ScienceDirect

Health & Place

journal homepage: www.elsevier.com/locate/healthplace

Natural movement: A space syntax theory linking urban form and function with walking for transport

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ARTICLE INFO

Keywords:
Urban design
Street layout
Destinations
Active travel
Neighborhood
Land use

ABSTRACT

Walking to get to and from local destinations including shops, services, and transit stops is a major source of adults' health-related physical activity. Research has been using space syntax measures in examining how urban form is related to such routine walking for transport. This paper proposes to apply a theory of space syntax, *natural movement*, which posits street layout as a primary factor influencing pedestrian movement. Discussing how this theory can link urban form (street layout) and function (land use) with walking for transport, we propose a research agenda to produce new insights and advance methods in active living research.

1. Background

1.1. Built environment and walking for transport

Physical inactivity is one of the main contributors to the global public health burden of non-communicable diseases, particularly type 2 diabetes and cardiovascular disease (World Health Organization, 2017). Most urban-dwelling adults are, however, insufficiently active for preventive health benefits (Hallal et al., 2012). Walking for transport to get to/from local destinations including shops, services, and transit stops is a major source of adults' health-related physical activity (Chaix et al., 2014) and consistently associated with better health (Kelly et al., 2014; Murtagh et al., 2010). Its health benefits can outweigh the associated risks of trauma through traffic incidents and exposure to air pollution (Mueller et al., 2015). Due to its potential to be integrated into daily life, walking is argued to be a practical and sustainable way to promote regular physical activity for improved health outcomes (Lee and Buchner, 2008). "Active living research," which aims to create activity-friendly communities, has shown that neighborhood built environment attributes are related to residents' walking for transport (Giles-Corti et al., 2016; Sallis et al., 2016; Sallis and Owen, 2015). In order to identify environmental features supportive of walking, the built environment first needs to be operationalized and measured. Over the past decades, this research field has developed several measurement methods to characterize such environmental attributes (Brownson et al., 2009; Eyler et al., 2015). A measure of "walkability" has been used widely: An index consisting of four components (residential density, land use mix, street connectivity, and retail site design) has been shown to be associated with walking for transport (Frank et al., 2010).

1.2. Street layout and land use: urban form and function

Street connectivity is a component of walkability related to urban form. It is concerned with street layout, in particular, the directness of routes between two locations (e.g., home and shopping venues) in a street network (Handy et al., 2003). It has typically been measured as intersection density (i.e., the number of intersections with 3 or more intersecting streets divided by area size), using street centerline data, which are commonly available from local governments, public sectors dealing with roads and water distribution, or an open source (e.g., OpenStreetMap, Google). Greater street connectivity has been found consistently associated with higher levels of walking (Badland et al., 2008; Koohsari et al., 2014b).

Land use mix, which refers to having a variety of services, retail outlets and other amenities within an area, represents a functional aspect of urban land. It is hypothesized that higher land use mix is conducive to more walking for transport, but literature reviews have shown inconsistent findings on the association of land use mix with walking

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https://doi.org/10.1016/j.healthplace.2019.01.002
Received 10 July 2018; Received in revised form 22 October 2018; Accepted 3 January 2019
Available online 11 January 2019
1353-8292/

for transport (Durand et al., 2011; Grasser et al., 2013). This may be partly because land use mix relates to the presence of different uses (any land uses) rather than to the presence of specific land uses that may provide destinations for walking. There are also issues of data availability and comparability. Calculating land use mix requires parcel-level land use data, which are often difficult to obtain or unavailable (Lotfi and Koohsari, 2011; Salvo et al., 2014). Another issue is the comparability of base land use data: different sets of land use categories are often used in different localities. Producing land use mix measures comparable across areas can be challenging, even when land use data are available (Mavoa et al., 2018).

1.3. Space syntax as a measure of street connectivity

Space syntax offers an alternative way of measuring street connectivity. Originating from architecture and urban design, space syntax is commonly understood to be a *method* to characterize and quantify the spatial layout of enclosed spaces within buildings or streets within urban space, using topological approaches (Hillier and Hanson, 1984; Hillier et al., 1987). Unlike intersection density, space syntax measures focus on topological distance within a network, i.e., the number of turns that are needed to reach from one location to another (Bafna, 2003; Peponis et al., 1997). The process for calculating space syntax measures has been explained elsewhere (Bafna, 2003; Hillier and Hanson, 1984; Koohsari et al., 2014a; Peponis and Wineman, 2002), and will not be described in detail here. Briefly, street integration, a key space syntax measure, shows how "accessible" a street segment is topologically from all other street segments within a defined area (e.g., a certain distance from the center of the street). A higher integration value for a street segment means that fewer turns are required to reach the segment from other streets within the network. Fig. 1-a shows a street network, and Fig. 1-b shows the levels of integration (darker lines are higher in integration). Similar to intersection density, space syntax measures can be calculated based only on street centerline data, using a specifically developed yet open software (Turner, 2004).

Space syntax measure have been used as an indicator of street connectivity in active living research (Baran et al., 2008; Koohsari et al., 2017a). This entails an additional step, as this area of research is concerned with environmental attributes at the scale of neighborhood. Since space syntax measures are calculated for each street segment, they need to be aggregated into an area-level measure (e.g., a "buffer" area within a certain distance from home, an administrative area unit); so that their association with walking can be examined (Fig. 1-c). Street integration aggregated at this level has been found associated with walking in the U.S. (Baran et al., 2008) and in Japan (Koohsari et al., 2017b).

2. Aim

To date, active living research has employed the *methods* of space syntax as an alternative to intersection density. We argue in this article that a *concept* of space syntax, natural moment, can help advance our understanding of the role of street layout in active living research. The theory of *natural movement* identifies street layout as a primary factor influencing pedestrian movement within a city (Dhanani et al., 2017; Hillier et al., 1993; Karimi, 2012; Omer and Goldblatt, 2016). Although space syntax methods "were not originally aimed at modelling movement but at understanding the morphological logic of urban space" (Hillier et al., 1993), the theory of natural movement can move active living research forward conceptually, because it provides a link between urban form, function, and walking for transport.

While there have been two previous commentaries in active living research introducing the utility of space syntax in relation with children's physical activity (Cutumisu and Spence, 2009) and adults' park-related physical activity (Koohsari et al., 2014a), they have primarily focused on how to apply space syntax measures. They do not address explicitly the potential for conceptual advancement building on the theory of natural movement. In the below, we first explain the theory of natural movement, and illustrate how well-connected street layout (urban form) enhances walking for transport (pedestrian movement) partly through attracting retail land use (urban function). We then propose four key research issues that emerge as a result of explicitly incorporating the theory of natural movement in active living research.

3. Natural movement

3.1. A theory linking urban form and function with pedestrian movement

Natural movement, a theory within space syntax, refers to the ability of street layout itself to predict pedestrian movement (Hillier et al., 1993). The theory posits that more integrated streets, which are likely to be more accessible from other streets, will draw more

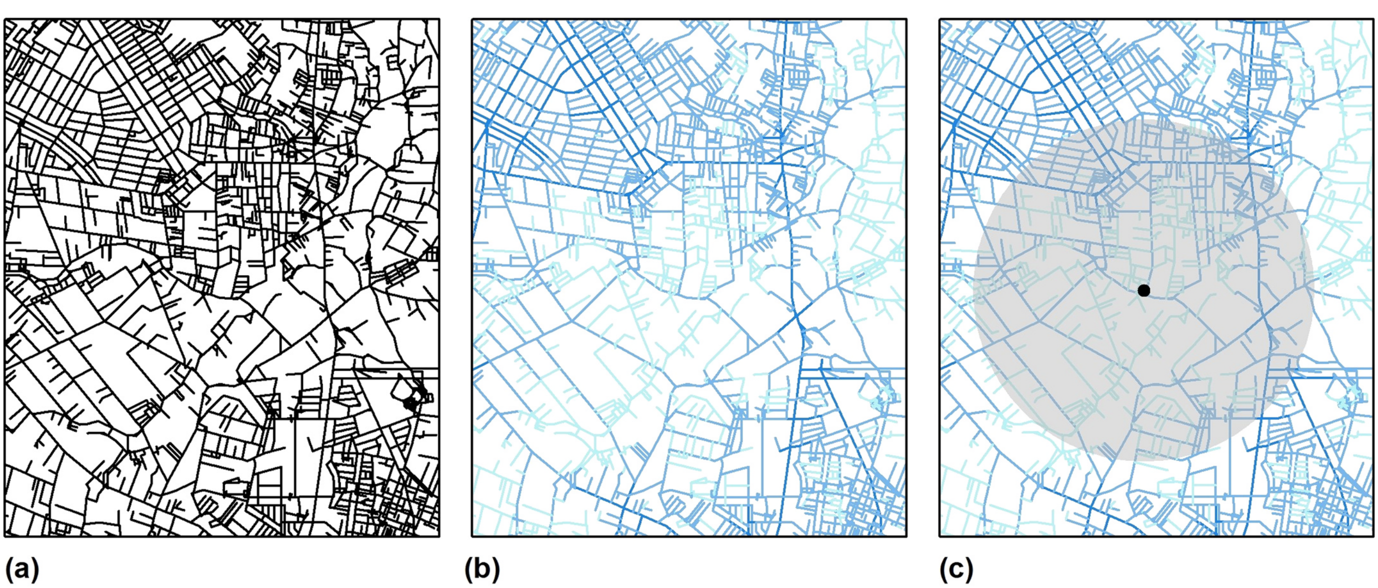

Fig. 1. Process of calculating space syntax measures: (a) street centerlines (base map); (b) space syntax measure of integration calculated for each street segment (darker lines are more integrated), (c) area-level measures calculated by aggregating integration values within a buffer area from participant's home.

pedestrians. A positive correlation between higher street integration and a greater pedestrian volume has been found in several previous studies (Foltête and Piombini, 2007; Hajrasouliha and Yin, 2015; Hillier and Iida, 2005; Lerman et al., 2014; Ozbil et al., 2011). There are also established associations of higher intersection density with more walking for transport (Badland et al., 2008; Christiansen et al., 2016; Koohsari et al., 2014b). An often-used explanation for such associations is that travel distance is shorter between two points in areas with well-connected streets (Frank, 2000). However, according to the natural movement theory, what contributes to more pedestrian movement in areas with better street connectivity is co-location of commercial and public buildings along more integrated streets (Hillier et al., 1993). Empirical studies have indeed shown the association of street integration with the availability of commercial land uses or commercial destinations (Liu et al., 2015; Omer and Goldblatt, 2016; Porta et al., 2012; Rui and Ban, 2014; Tsou and Cheng, 2013; Wang et al., 2014). It has been also shown that areas with well-connected streets are conducive to transportation walking, in part due to availability of more commercial destinations (Koohsari et al., 2017a, 2016b).

Although space syntax methods focus strictly on how streets are connected topologically, it is the theory of natural movement that can link the formal and functional aspects of urban land through pedestrian movement (Hillier et al., 1993). In this regard, the theory of natural movement bridges street layout and destinations (land use), two important environmental elements supporting transportation walking (Millward et al., 2013; Sugiyama et al., 2012; Wineman et al., 2014; Witten et al., 2012). Fig. 2 depicts how built environment factors (form and function) are integrated by the theory of natural movement and influence transportation walking through pedestrian movement.

4. Research agenda

Applying the theory of natural movement to active living research opens up new research avenues to be investigated. We propose the following four topics to gain new insights and advance methods in active living research.

4.1. Extending the applications of space syntax as a parsimonious and practical tool for characterizing key attributes of walkability

The theory of natural movement and supporting empirical findings (higher integration means not only higher street connectivity but also the presence of commercial destinations) point to a possibility of using street integration as a new measure of walkability. The walkability index commonly consists of net residential density, street connectivity, mixed land use, and retail site design (Frank et al., 2010). As discussed before, parcel-level land use data are hard to locate, and the data-intensive nature of the walkability index may in some contexts limit its broader applications. Developing high-quality, yet less data-dependent environmental measures in relation to walking is important to widen

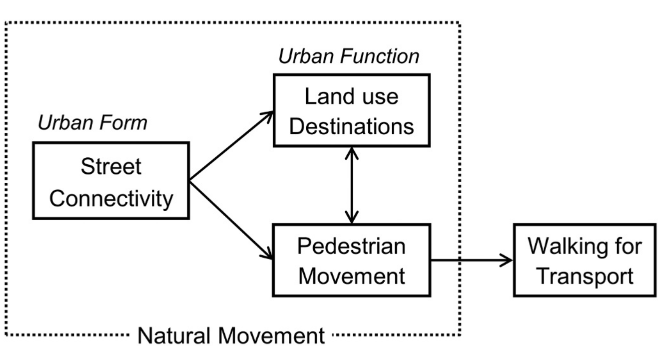

Fig. 2. Diagrammatic representation of the theory of natural movement and walking for transport.

the research base for urban design and public health.

To address the gap, Koohsari et al. (2016a) developed a new walkability index, space syntax walkability (SSW), based on the space syntax theory of natural movement. This index consists of population density and a space syntax measure of integration, which is not only a measure of street layout but can also represent the presence of commercial land use or destinations. As discussed above, street integration is calculated using commonly-available street centerline data with open software. Thus, SSW can be a less data-intensive version of walkability. It has been shown that SSW and the four-component walkability are highly correlated ($\rho = 0.76$) and equally associated with walking for transport in a study conducted in Australia (Koohsari et al., 2016a). Future research needs to examine how SSW is correlated with walkability and associated with walking for transport in different localities. Once confirmed, SSW can be used as a simplified measure of walkability for areas where detailed land use data are not easily available. It is important to note that walkability is a relative (ranking) measure that is determined within a certain study area. This also applies to street integration, which does not have a unit. In contrast, a more recent measure, Walk Score, is on an easily interpretable scale (www.walkscore.com). To facilitate the broader utility of SSW not only by researchers but also by practitioners, research needs to develop a benchmark against which the level of walkability can be judged.

4.2. Conducting street-level investigations of integration and GPS-based walking

Active living research has been using "neighborhood" as an area-level unit. Neighborhoods are defined either as an area within a certain distance (buffer) from participant's residential address or within existing administrative boundaries (e.g., Census Block in the U.S., Output Area in the U.K., Statistical Area in Australia). All environmental factors are calculated within such areas, and analyses examine how these area-level measures are associated with residents' physical activity. However, defining a neighborhood is not an easy task. It has been shown that buffer areas typically used in research do not match an area considered as "neighborhood" by residents (Smith et al., 2010) or an activity space captured by global positioning systems (GPS) where their physical activity takes place (Holliday et al., 2017; Kwan et al., 2018). It is also known that the level of associations between walkability measures and walking differs by the way buffers are drawn (Houston, 2014; Koohsari et al., 2013; Oliver et al., 2007). As discussed above, there are two stages in calculating area-based space syntax measures: the first stage is to calculate integration for each street segment, then the second stage is to calculate the mean integration for a neighborhood. Both stages require a defined area, in which calculation is to be performed. In principle, the size of these areas should align with the distance that can be walked. However, walkable distances vary by demographic factors, and different sizes specified can produce different space syntax measures. This is the modifiable unit area problem (MAUP), a well-known problem in geography, where any change of boundary in which data are aggregated may produce different results (Openshaw, 1984).

Space syntax measures can transform the way in which relationships between environmental factors and walking are examined, as they allow consideration of the relationships at the scale of streets. Examining how street-level integration is related to pedestrian volume is now possible due to an increasing use of new tracking technologies such as GPS in mobile phones and wearable devices (Althoff et al., 2017; Krenn et al., 2011; Shoval, 2008). Such research may provide a more detailed understanding of street-level attributes that may affect walking for transport.

4.3. Conducting natural-experiment studies

The majority of evidence showing relationships between space syntax measures and walking comes from cross-sectional studies. At this point, it is only possible to conclude that environmental attributes identified by space syntax are "correlates" of adults' walking for transport. There are a few longitudinal studies examining participants' walking before and after they relocated, which found that moving to areas with better street connectivity was associated with an increase in walking (Knuiman et al., 2014; Wells and Yang, 2008). A cohort study following participants over nine years also found that street connectivity did change during the study period, and improved connectivity was associated with increased walking for transport (Hirsch et al., 2014).

Although street layout is highly stable in existing neighborhoods, it does change occasionally. For instance, an infill development may have new streets/paths that connect existing streets. A new park or open space can also link adjacent streets. An addition of such new street segments could change street integration values substantially. Evidence from natural experiments observing such changes to the street network would be highly informative, as this would provide strong indications of causality.

4.4. Testing the theory of natural movement

As shown in Fig. 2, the space syntax theory of natural movement links street layout and land use with pedestrian movement. In the actual environment, this occurs as an incremental process, in which economic activities and pedestrian movement gradually build up along well-connected streets (Omer and Goldblatt, 2016; Scoppa and Peponis, 2015). The process of co-location of retail destinations and integrated streets can be also assisted by agglomeration of commercial destinations and services, which can enhance efficiency and convenience of access. It is possible to track such commercial activities over time through various means (e.g., yellow pages, business registration databases). Identifying where commercial destinations increased or decreased according to space syntax measures can be informative not only to research on active travel but also to land use planning. Commercial land use is not always allocated along well-connected streets due to land use zoning. Understanding the characteristics of streets where commercial activities are more likely to grow will help policy-makers and practitioners to make informed decisions about where best to locate commercial and residential land uses.

Research can also examine how mismatch between land use and street integration (e.g., commercial land use along less-integrated streets) is associated with less walking for transport, in comparison to areas where there is a match. Such research can further testify to the importance of understanding the role of street layout in building neighborhoods that facilitate walking.

5. Conclusions

Space syntax methods show considerable promise as a parsimonious approach to measuring aspects of urban form in relation to walking for transport. In this article, we have focused on the space syntax theory of natural movement, and explored new research avenues that may be opened up by applying this theory. As natural movement enables urban form and urban function to be linked with pedestrian movement as an underlying element, it can provide insights into street layout as a multidimensional determinant of walking for transport. Although space syntax has been used in urban design/planning, architecture, transport, and geography areas for decades, its application to health promotion (through walking) is still limited. Further studies are warranted to make more-explicit use of the theory of natural movement, and to apply space syntax methods to inform urban design/planning practices and policies that encourage walking for transport.

Acknowledgements

Koohsari was supported by a JSPS Postdoctoral Fellowship for Research in Japan (#17716) from the Japan Society for the Promotion of Science. Oka is supported by the MEXT-Supported Program for the Strategic Research Foundation at Private Universities, 2015–2019 the Japan Ministry of Education, Culture, Sports, Science and Technology (S1511017). Owen was supported by an NHMRC Program Grant [#569940] and a NHMRC Senior Principal Research Fellowship [#1003960].

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