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Identifying GIS Measures of the Physical Activity Built Environment Through a Review of the Literature

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Background: Examining relationships between features of the built environment and physical activity is achievable with geographic information systems technology (GIS). The purpose of this paper is to review the literature to identify GIS measures that can be considered for inclusion in national public health surveillance efforts. In the absence of a universally agreed upon framework that integrates physical, social, and cultural aspects of the environment, we used a multidimensional model of access to synthesize the literature. ***Methods:*** We identified 29 studies published between 2005 and 2009 with physical activity outcomes that included 1 or more built environment variables measured using GIS. We sorted built environment measures into 5 dimensions of access: accessibility, availability, accommodation, affordability, and acceptability. ***Results:*** Geospatial land-use data, street network data, environmental audits, and commercial databases can be used to measure the availability, accessibility, and accommodation dimensions of access. Affordability and acceptability measures rely on census and self-report data. ***Conclusions:*** GIS measures have been included in studies investigating the built environment and physical activity, although few have examined more than 1 construct of access. Systematic identification and collection of relevant GIS measures can facilitate collaboration and accelerate the advancement of research on the built environment and physical activity.

Keywords: geospatial, neighborhood, obesity, community design

Linked to obesity, a host of chronic diseases, and billions of dollars in healthcare spending each year, physical inactivity threatens to decrease the longevity of future generations and places further strain on a fragile healthcare system undergoing reform. In population studies, the etiology of physical inactivity and its inverse—physical activity engagement—is commonly examined through the interrelationships of personal, social, and built environment factors that influence behavior.[1] These interrelationships can be modeled through theory-based frameworks that attempt to conceptualize multiple influences on physical activity behavior.

Early research in the area of built environments and health relied on subjective measures of the environment collected through self-report instruments. Today, examinations of this complex relationship can be augmented by objective measures obtained using geographic information systems (GIS) technology. GIS integrates, analyzes, and maps data linked to time and location. The data are organized in layers, with each data layer containing information on a single environmental feature (eg, a public transportation network, geographically-coded park locations within a community).

GIS has become an invaluable tool for studying the relationship between the built environment and physical activity. Combined with measures of individual physical activity behavior collected by accelerometry and global positioning system (GPS) devices, observation, or self-report instruments, GIS has been used to test for associations between a number of built environment features and physical activity. As this area of research has evolved and the evidence linking the built environment to physical activity has become replete, researchers[2] and government agencies[3] have called for a nationally coordinated approach for collecting and analyzing basic GIS data layers as part of routine public health surveillance. Protocols have been developed that describe best practices for collecting and coding measures of the built environment,[4,5] and adhering to these recommendations would facilitate harmonization of geospatial data across regions and collection sites. However, despite the availability of guidance for obtaining GIS data and calls from experts for theory-based approaches to characterize the built environment,[6] there is wide variability in how GIS variables are constructed to represent built environment concepts.

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Conceptual Models of Physical Activity in the Built Environment

Built environment and physical activity research is rooted in health, exercise, and behavioral sciences; urban planning; and recreation studies. Each field has contributed conceptual models and measurement techniques to study the built environment's role in physical activity behavior, although many of these ideas have yet to be integrated across disciplines. Early adopters in the area of built environment and physical activity research made substantial progress in delineating features of the environment linked to physical activity. Such examples include Pikora et al's model of 4 built environment facets associated with physical activity (function, safety, aesthetics, and destinations)[7] and Cervero and Kockelman's 3D's (density, diversity, and design).[8] Although these classification schemes are useful for describing the presence or absence of built environment features, they were not designed to characterize human spatial behavior and access to opportunities for physical activity engagement.

Questions relating to access and standardized metrics have been raised by a number of physical activity environment researchers. Literature reviews and special papers on GIS, physical activity, and the built environment have pointed to several key themes: the absence of testable conceptual models to study people, behavior, and place,[9] building a theoretical framework to identify characteristics of the built environment that may influence physical activity based on existing urban design literature,[6] using mixed-methods approaches to assess objective and subjective measures,[6] and calling for refinement of built environment measures.[10]

Fundamentally, the objective of investigating the built environment's role in physical activity behavior is to define access to physical activity opportunities so that appropriate public health action can be taken to facilitate and increase physical activity engagement while decreasing disparities in access. The purpose of this paper is to review the literature on the built environment and physical activity to identify GIS measures that can be considered for inclusion in national public health surveillance efforts. In the absence of a universally agreed upon framework that integrates physical, social, and cultural aspects of the environment, we used a multidimensional model of access to synthesize the literature.

Methods

Evidence Acquisition

For this systematic review of the literature, we identified studies of adult populations that used GIS data to test a hypothesized association between the built environment and physical activity. We characterized indicators of physical activity from each study using a conceptual model for access (described below). Articles included were published in English-language peer-reviewed journals between January 2005 and December 2009. Before 2005, few health researchers used GIS to study the built environment's association with physical activity behavior.[11] As a result, the 5-year interval designated in our review was expected to yield the most sophisticated analyses to date because they were built on earlier research. We identified articles by keyword search using the following online databases: Web of Knowledge, PubMed, PsycINFO, and Scopus. In addition, to capture articles not indexed in these databases, we searched journals recognized for examining associations between the built environment and health, transportation, or community planning. These included *Environment and Planning, International Journal of Health Geographics*, *Journal of the American Planning Association*, *Transportation*, *Transportation Research—Parts A and D*, *International Journal of Sustainable Transportation*, and *Urban Studies*.

We employed a Boolean search strategy with keywords as follows: ("GIS" OR "Geospatial") AND ("Physical Activity" OR "Exercise" OR "Walking" OR "Walkability" OR "Cycling" OR "Public Transit"). We retained studies that used GIS methods to explore the relationship between the built environment and physical activity using a cross-sectional study design. Specifically, we included articles whose dependent variable measured engagement in a specified type of physical activity at a single point in time and whose independent variables included 1 or more measures of the built environment characterized using GIS.

We abstracted data from each article using a standardized format to describe the study's geographic location and scale of analysis; measurement instrument, mode, and outcome measure; and independent variables characterized as different dimensions of access. In an effort to compare measures across studies, we abstracted information describing how each study's independent variables were developed (eg, combination of GIS layers, novel algorithm). We also abstracted summary statistics where significant associations with physical activity outcomes were reported. For studies that included multiple regression models, we reported summaries from the saturated model or the best model as determined by the respective researchers. Analysis of this growing body of literature on physical activity and the built environment requires increased specificity in linking built environment features to physical activity purpose.[12] Therefore, we presented a summary of each study's findings with respect to physical activity domain: total physical activity, leisure-time physical activity, and transportation physical activity.

Conceptual Model of Access

To characterize the different dimensions of access captured in the literature, we used a model previously described by Penchansky and Thomas.[13] These authors defined access as the degree of fit between the characteristics and expectations of users and the characteristics of a system, partitioned into 5 closely related but distinct dimensions: availability, accessibility, accommodation, affordability, and acceptability.[13] For the purpose of this review, we considered the "clients" as the individuals within a community and the "system" as the community's built and social environment. We adapted this model for investigations of the built environment and physical activity behavior. In our adaptation, Penchansky and Thomas' 5 dimensions of access are interpreted and defined as follows:

1. Availability: Adequacy of the supply of resources for physical activity engagement and proximity to common destinations. From a functional standpoint, this includes features and spaces where physical activity takes place and close proximity (ie, within neighborhood boundary) to common destinations such as parks and retail centers that can be accessed by nonmotorized travel.
2. Accessibility: Built environment features (eg, street networks, pedestrian networks) that facilitate movement toward available destinations.
3. Accommodation: Ancillary features of the built environment that are objectively measured for describing how favorable the environment is for physical activity engagement. The accommodation dimension includes environmental features such as safety, aesthetics, and sidewalk conditions.
4. Affordability: Includes population-level socioeconomic status (SES) measures or measures that serve as proxies for population-level SES or income (eg, median income per census tract). This dimension has utility for identifying social disparities to access for physical activity opportunities.
5. Acceptability: The extent to which the built environment is perceived as suitable to the needs of individuals for physical activity engagement. Such measures include, but are not limited to, subjective measures or perceptions of the built environment and preferences with respect to neighborhood selection measured through self-report instruments.

Results

Evidence Synthesis

A keyword search of online databases and targeted journals yielded 436 articles. We limited the review to articles where the outcome of interest was a measure of physical activity engagement and independent variables included 1 or more GIS measure of the built environment (articles about data validation, methodological considerations, and GIS database construction were excluded). As a result, we identified 29 eligible studies published between January 2005 and December 2009.[14–42] The number of published articles meeting these criteria increased each year suggesting a burgeoning interest in the use of GIS to study the relationship between the built environment and physical activity. Table 1, which is viewable online at http://tinyurl.com/24o3rep, presents a synopsis of the data abstracted from each paper including a summary of each study's findings with respect to specific physical activity domains. Most studies were performed in the United States (n = 18), followed by Australia (n = 5), the United Kingdom (n = 2), Canada (n = 1), Colombia (n = 1), Japan (n = 1), and New Zealand (n = 1).

Thirteen studies measured outcomes for total physical activity mediated by variables characterized along the 5 dimensions of access.[14,15,19–21,25,30,32,35,37,39,41,42] In a similar fashion, leisure-time physical activity[14,16,18–22,24,25,27,29–31,34,39–41] and transportation physical activity[17–23,25–28,30,32,34,36,38,39] were assessed in 17 of the studies in our review. With the exception of one study,[36] the geographic scale of analysis ranged from a one-quarter mile to a 3 mile radius about the study participant's geocoded home location. This scale defined the neighborhood boundary and provided the basis for measures of access. No study measured all 5 dimensions of access.

Penchansky and Thomas' 5 Dimensions of Access by Physical Activity Domain

Measures of Availability. Among measures of availability, higher land-use mix, availability of green and open space, and close proximity to common destinations were associated with higher total physical activity.[15,32,35,37,41] In addition, residing in a traditional neighborhood compared with a suburban neighborhood resulted in higher levels of cycling and walking.[37] Similar to findings for total physical activity, diversity in land-use mix and availability of green and public open space were associated with higher levels of leisure-time physical activity.[15,22,24,29–31,33,34,38] Increasing distances to schools, workplace, and grocers among a host of other destinations, were associated with lower leisure-time physical activity.[33] Land-use mix, proximity to natural amenities, and proximity to common destinations were the prevailing availability measures associated with physical activity for transportation.[17,22,28,30,32,34,36]

Measures of Accessibility. Objective measures of accessibility generally did not appear to play a significant role in total physical activity engagement among the studies in our review. The presence of sidewalks emerged as the only accessibility indicator of higher physical activity for this domain.[42] Measures of accessibility associated with leisure-time physical activity included sidewalk coverage and street connectivity.[27,30] Street pattern and access to public transit stops were the most common measures used in testing for associations with transportation physical activity. Street pattern—assessed by density of intersections and number of access points per street segment—was positively associated with transportation physical activity.[26,27,30,32,38] A higher number of transit stops was also associated with higher levels of activity.[30,34] Features negatively associated with transportation physical activity included features that impede movement such as the presence of 3-way intersections.[30]

Measures of Accommodation. In contrast to measures of accessibility, measures of accommodation were frequently shown to be associated with total physical activity. Higher levels of objectively measured safety and comfort (eg, presence of crossing aids) were positively associated with total physical activity behavior.[25,30] Higher traffic volume was also associated with higher levels of activity in this domain.[35] In this context, traffic volume may have reflected the attributes of a highly dense or urban area. Similarly, street segments with visible litter, graffiti, and dumpsters—elements also associated with densely populated metropolitan areas—were associated with higher physical activity for total physical activity. With respect to the leisure-time physical activity domain, higher neighborhood safety, higher traffic safety, and aesthetically appealing communities were positively associated with physical activity engagement.[21,25,31,35,40,41] Though comfort (eg, sidewalk condition) was measured across multiple studies, no significant relationship with leisure-time physical activity was observed. Higher land-slope was associated with lower physical activity for transportation.[38]

Measures of Affordability. Population-level measures of affordability were rarely examined in the studies we reviewed and not at all in relation to leisure-time physical activity. Neighborhood-level SES, median home value, and income were measured directly in a few studies, but none emerged as significant correlates of physical activity. The percentage of African Americans was used as a proxy for SES in one study and was considered a measure of affordability for our review because the concept of affordability includes measures of social disparity with regard to physical activity access. In this study, a higher percentage of African Americans was associated with a lower level of physical activity.[32]

Measures of Acceptability. Perceptions of available destinations (eg, perceived proximity to workplace) and neighborhood selection for physical activity attributes[18,23] were strong indicators of total physical activity. Populations that perceived their neighborhoods to be clean also reported higher total physical activity.[14] Aesthetics (measured via a Likert scale for subjective greenness and positive perceptions of footpath conditions) were associated with substantially higher levels of leisure-time physical activity when compared with the respective reference groups.[14,24] Acceptability markers for transportation physical activity included perceived access to destinations within a 5 minute walk, perceived proximity to workplace, and neighborhood selection for physical activity attributes.[18,23] Across all 3 domains, favorable observations of the natural and built environments resulted in higher physical activity. Such observations included "lack of trees is not a problem," "hills are not common," and "lack of crosswalks is not a problem".[20,21]

Conclusions

In this systematic literature review, we examined studies that tested hypothesized associations between features of the built environment and physical activity. These studies were distinguished by their use of GIS to provide objective measures of the built environment that may act as mediators of physical activity behavior. As evidenced by the distribution of studies included in our review, with the heaviest concentration of articles being published between 2007 and 2009, interest in, and use of, GIS as a tool to develop objective metrics of the built environment is burgeoning. However, the lack of standardization among built environment definitions creates a challenge for public health researchers and practitioners and hampers their ability to synthesize evidence and identify environmental features that may explain physical activity behavior. We explored the adaptation and application of Penchansky and Thomas' conceptual framework for access to built environment and physical activity research.

The findings of this literature review indicate that when GIS measures have been included in studies investigating the role of the built environment and physical activity, few have examined more than 1 construct of access. The constructs that were most commonly measured were availability and acceptability. Constructs were often operationalized differently across studies. Greater attention to the common use of high quality measures could enhance future efforts to synthesize evidence across studies.

The 5 Dimensions of Access

Penchansky and Thomas modeled access as a function of 5 dimensions: availability, accessibility, accommodation, affordability, and acceptability. Our application of this framework for physical activity and the built environment rests on the assumption that when all dimensions are satisfactorily present, populations have access to and subsequently use the built environment for physical activity purposes to a greater extent.

Measures of *availability* linked to physical activity engagement include composite measures of land-use mix, network distance to common destinations, presence of green and open space, diversity of destinations, and population density. Aside from population density, each measure requires knowledge of the spatial distribution of common destinations (eg, retail locations, institutional locations) or land use (eg, residential land use, recreational land use). Accordingly, a geospatial database developed for surveillance of availability in the physical activity environment would require GIS layers that accurately detail the proportion of land dedicated for a specific use and the geocoded locations of destinations. Probable data sources include tax assessor land use data and data from commercial databases. Although these are the most readily available solutions, they may not provide the level of accuracy needed for geospatial analyses; tax assessor data tend to be crudely measured and commercial databases are not likely to be comprehensive or current with regards to businesses opening and closing. Technological advances in data collection and development of data for research purposes are needed.

Population density—defined here as a proxy for the availability of resources linked to physical activity—can be measured as the census population count divided by the land area of interest. Though conceptually simplistic, a variety of measures for population density exist including those adjusted for population centroids or areas that include a higher proportion of residents compared with other areas within a census tract. As such, land area and population surveillance that allows for increased precision along multiple scales of analysis would provide the most effective investigations of population density as a mediator of physical activity behavior.

Measures of *accessibility* linked to physical activity engagement include street connectivity, global and local integration (proxies for accessibility), and street density. Each measure is constructed from available street network data. Surveillance of accessibility for physical activity engagement relies on accurate street network data in the form of GIS street layers. Street layers are typically available at the local government level but vary in accuracy and completeness.

The presence of sidewalks was also shown to have an association with physical activity engagement. Unlike street networks, geospatial data for pedestrian networks (eg, sidewalk coverage, bike paths) are not readily available from public or private sources. However, instruments such as the Systematic Pedestrian and Cycling Environmental Scan (SPACES) or Pedestrian Environment Data Scan (PEDS) can be used to map walking and cycling environment. A collaborative network that allowed for the sharing of data systematically collected using reliable and valid instruments such as these would make for a robust addition to a surveillance system for the physical activity environment.

Though measures of *accommodation*, *affordability*, and a*cceptability* are not features specific to the built environment, their attributes were geocoded for evaluation alongside GIS measures. Our review highlighted a number of accommodation features associated with physical activity including safety, comfort, and aesthetics typically obtained through environmental audits. Few studies measured affordability at the population-level. However, these measures rely on available sociodemographic data via the census. Valid and reliable survey instruments are needed to collect measures of acceptability for individual-level measures including perceptions of the built environment.

We recognize a number of limitations in our literature review. Beyond geocode matching, few studies in our review described the validity of their datasets. In addition, data sources varied across studies. Many studies were performed in areas whose local governments had rich GIS datasets. In addition, by focusing our literature search on studies using the keywords "GIS" and "geospatial" we may have inadvertently failed to identify some studies of the built environment and physical activity; however, our primary objective was to examine GIS-based measures of the built environment, hence our choice of search terms. Finally, the Penchansky and Thomas model has been used to examine multiple dimensions of access for diverse outcomes, but other conceptual frameworks can be used to characterize access in the physical activity built environment.

The Utility of Geospatial Data for Physical Activity Environment Surveillance

Geospatial data has helped shape the national agenda by identifying environment-level variables that are associated with health outcomes. In response to the pressing public health challenge of childhood obesity, President Obama issued a memorandum detailing the establishment of a federal Task Force on Childhood Obesity for the express purpose of securing access to healthy, affordable foods and increasing physical activity in schools and communities.[43] Development of this task force was accompanied by the First Lady's *Let's Move* initiative seeking to secure access to healthy, affordable foods and increase physical activity in schools and communities. In addition, the USDA has developed the Food Atlas (http://www.ers.usda.gov/foodatlas), a geographical representation of the food environment across the nation, which allows researchers to identify vulnerable areas known as "food deserts." A similar tool mapping the physical activity environment would prove to be an invaluable resource for scientists, policy makers, and other interested stakeholders in highlighting areas of intervention for physical activity.

Two main types of objective data can be used to study how the built environment affects physical activity behaviors: audits conducted by individual researchers and secondary data, such as those provided by government GIS sources. Collecting on-the-ground data from audits requires substantial effort, making use of secondary data an attractive option. It has been reported that geographic location is a feature of 80 to 90% of all government data,[44] and publicly accessible GIS data layers are collected at local, state, and national levels. However, the number, quality, and completeness of data layers depend on the resources and policy priorities of the agencies that collect and warehouse the information. Some areas have excellent and accessible data, while others still have paper-based or nonexistent data. Even in areas with accessible data, the descriptors of environmental variables used are not comparable. At this point, GIS data sharing for physical activity research applications is casual and opportunistic, impeded by lack of infrastructure, collaboration, and training.[45]

The utility of GIS for examining physical activity outcomes in the built environment depends on easily accessible research-quality data. Researchers are challenged by the absence of a shared and standardized infrastructure to facilitate national surveillance of the physical activity environment to advance research, programs, and policy. Cyber infrastructures, such as NCI's caBIG (cancer Biomedical Informatics Grid: https://cabig.nci.nih.gov), are already in place to warehouse GIS datasets and facilitate collaboration between scientists. In addition, the International Physical Activity and Environment Network (https://www.ipenproject.org) provides an example for sharing global data based on ecological models of health behavior. New standards and protocols are needed for the acquisition, analysis, and sharing of geospatial data related to the physical activity environment. This includes (1) defining necessary basic geospatial data layers for core measures of the physical activity environment, (2) developing and demonstrating a process for data collection and harmonization to create common data elements in compatible electronic formats with specifications for metadata, (3) defining the process for validating geospatial data layers, (4) developing an open-access framework for data sharing, (5) developing data analysis applications to facilitate merging data and complex data analysis, and (6) developing a strategy for ongoing communication and dissemination of geospatial data/open-access framework. Procedures for determining measurement error in geospatial data also are needed in addition to considerations for spatial and temporal resolutions.

The relationship between community design and physical activity behavior has garnered interest from city planners to epidemiologists seeking to identify built environment features that promote bodily movement for health, transportation, and recreation. During the 1980s, the transportation and urban planning industries examined the effects of land-use and community design on travel behavior with the goal of reducing traffic congestion and air pollution through increased nonmotorized transportation.[46] Density, diversity, and design served as gold standard metrics for modeling transportation options at the population level. Although the transportation paradigms of the 1980s did not address health benefits of physical activity, the 1990s brought about a new interest in the link between physical activity, health, and community infrastructure. Such interconnectedness calls for the use of more fully defined frameworks that can be used to explore the varied influences on physical activity behavior.

With increased interest in the relationship between the built environment and physical activity, it is vital that we move toward standard definitions to characterize this relationship. In a review on the state of the science for measuring features of the built environment, Brownson et al[47] called for routine collection of critical, basic GIS data layers for public health surveillance. This idea has been echoed by the US Centers for Disease Control and Prevention in a call to leverage the vast amount of government-assembled geospatial data.[3] The CDC panel cited a need to "spatially enable and strengthen public health surveillance infrastructure," "develop metrics for geospatial categorization of community health and health in equity," and "evaluate the feasibility and validity of standard metrics of community health and health inequities." Doing so will accelerate progress toward a comprehensive approach to monitoring physical activity behavior among Americans and improving the health of communities.

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