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Effects of Buffer Size and Shape on Associations between the Built Environment and Energy Balance

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Abstract

Uncertainty in the relevant spatial context may drive heterogeneity in findings on the built environment and energy balance. To estimate the effect of this uncertainty, we conducted a sensitivity analysis defining intersection and business densities and counts within different buffer sizes and shapes on associations with self-reported walking and body mass index. Linear regression results indicated that the scale and shape of buffers influenced study results and may partly explain the inconsistent findings in the built environment and energy balance literature.

Keywords

Built environment; walking; body mass index; geographic information systems; spatial uncertainty

1. Introduction

High levels of obesity are a pressing problem, costing the United States approximately \$147 billion in healthcare costs annually (Finkelstein et al., 2009). Additionally, physical inactivity contributes to approximately 6.7% of the burden of disease due to coronary heart disease and 8.3% of the burden of disease due to type 2 diabetes, and causes 10.8% of premature mortality in the United States, on par with smoking in terms of preventable causes of disease (Lee et al., 2012). Individual lifestyle choices undoubtedly influence obesity and physical activity; however, researchers have begun exploring contextual influences on these energy balance outcomes as predicted by ecological models of behavior change (Sallis et al., 2006, Moos, 1976, Sherwood and Jeffery, 2000, Sallis and Owen, 1997). Specifically, factors of the built environment, such as nearby destinations to walk to or well-connected streets that create efficient routes to reach those destinations, may create opportunities for higher levels of walking and lower levels of obesity (Handy, 2005). This approach is predicated on the concept that there is a relevant spatial context at which the environment affects an individual's behavior. This paper explores how different definitions of spatial contexts can influence analytical results.

The findings in research on the built environment over the last decade have been inconsistent. A recent review of the literature of the built environment and obesity revealed that about half of reported associations were null and there was very little between-study similarity in methods, preventing pooled estimates of effects (Feng et al., 2010). This heterogeneity in methodology across studies is an impediment to understanding the totality of the evidence of the built environment's impact on obesity.

Early studies defined an individual's exposure to the built environment based on administrative boundaries, such as counties, census tracts, or ZIP codes (Rundle et al., 2007, Mujahid et al., 2008, Lopez, 2007, Joshu et al., 2008, James et al., 2013, Ewing et al., 2006). A recent literature review by Leal and Chaix (2011) on the relationship between geographic environments and cardiometabolic risk factors revealed that 73% of studies reviewed relied

on administrative boundaries to assess exposure. While these measures are convenient because statistics are often gathered using administrative boundaries and privacy legislation often prohibits the release of datasets that include personal identifying information, there is an implicit assumption that administratively defined neighborhoods are an accurate and adequate representation of a “true” causally relevant spatial context (Foster and Hipp, 2011). Approaches that disregard the spatial unit in which study participants live and work may introduce significant measurement error and may decrease statistical power of contextual analyses and bias effect estimates (Spielman and Yoo, 2009). For instance, an individual may live on the edge of a census tract and may actually spend the majority of his/her time in an adjacent tract. Additionally, the use of administrative boundaries to define the built environment can lead to the modifiable areal unit problem, where the results of statistical analysis may differ according to the scale and pattern of the areal units chosen (Flowerdew et al., 2008, Flowerdew, 2011, Haynes et al., 2007).

In order to measure a closer approximation of an individual’s relevant spatial context, a method has emerged to define the built environment context through spatial units around geocoded home addresses. This method involves creating an area around a given distance from a home address. Researchers then use this spatial unit, an individual residence-based buffer, to define built environment measures for each individual. There are two dominant approaches to creating to assess the built environment (Figure 1). Radial, or Euclidean, buffers are created by drawing a straight line out a given distance from a home address and creating a circle that is used to define the built environment (Berke et al., 2007, Rutt and Coleman, 2005, Nelson et al., 2006). While radial buffers may theoretically be more representative of the built environment that may influence behavior compared to administrative boundaries due to the issues outlined above, radial buffers may be less likely to represent the “true” relevant spatial context in areas with natural features such as bodies of water or built features such as railways or poorly connected roads. In these situations, areas within the radial buffer may be included in the calculation of built environment measures but may actually not be accessible by the study participant (Oliver et al., 2007). An alternative approach is the line-based network buffer, where a line is traced a given distance from the home address via the street network (Forsyth et al., 2012). Small buffers (e.g., of 50m) are created around these lines to create a polygon of the traversable area within a given distance of the home address via the road network (Oliver et al., 2007). Line-based network buffers are thought to provide a more accurate representation of spatial context that would influence walking (Oliver et al., 2007, Boruff et al., 2012). The previously mentioned literature review by Leal and Chaix found that in studies that used buffers, 65% focused on radial buffers while the rest used a line-based network buffer approach. In the reviewed literature, the radius of circular buffers varied in area from 100 to 4800m, while network buffers varied between 640 and 2000m (Leal and Chaix, 2011).

Within each buffer, accessibility of walking destinations and street connectivity have been linked to walking (Handy, 2005, Sallis et al., 2012). It is hypothesized that accessibility of destinations provides opportunities for routine walking. As a measure of accessible destinations, counts or densities of businesses within a buffer have been used (Troped et al., 2013). Street connectivity could have influences on energy balance, as more connected street networks represent shorter distances between destinations and likely more dense

neighborhoods conducive to walking (Berrigan et al., 2010). Intersection counts within a buffer are a common measure of street connectivity, which is defined as the directness and availability of alternative routes from one point to another within a street network (Berrigan et al., 2010, Coogan et al., 2009, Coogan et al., 2011, Handy et al., 2002).

While line-based and radial buffers may more accurately represent the relevant spatial context that influences an individual's behavior compared to administrative boundaries, there is no uniform buffer length or shape used across studies (Leal and Chaix, 2011). Buffer parameters are loosely based on the transportation literature stating that an individual will walk up to 1600m to reach a destination, but it is unclear what the most appropriate spatial context is for understanding the relationship between the built environment and health. This lack of consistency in methods to define the buffers highlights the uncertain geographic context problem, defined by Kwan (2012b) as: "The spatial uncertainty in the actual areas that exert the contextual influences under study." This uncertainty refers to the lack of understanding of the "true causally relevant" area at which the environment exerts its influence on health. This uncertainty has implications in built environment and health research, as findings on the relationship between contextual variables and health outcomes can be impacted when the choice of geographic delineations of contextual units deviate from the true relevant geographic context (Kwan, 2012a). As explained by Diez Roux and Meir (2010), there is often little insight into the most relevant geographic context to answer a given research question. While information on these geographies comes primarily from qualitative studies, sensitivity analyses estimating the impact of varying definitions of spatial contexts on findings are necessary (Diez Roux and Mair, 2010). Previous studies have examined this topic in other settings and amongst other populations (Jones et al., 2010, Cockings and Martin, 2005, Cutchin et al., 2011, Parenteau and Sawada, 2011, Santos et al., 2010); however, no prior analysis has approached this issue at a broad geographic scale in a cohort of adult women.

To conduct a sensitivity analysis of the uncertain geographic context problem in built environment and health research, we examined how defining the built environment with different buffer sizes and shapes could influence associations with walking and body mass index (BMI). We hypothesized that measures of intersections (count and density) and businesses (count and density) would be positively associated with walking and negatively associated with BMI. We also hypothesized that effect sizes and statistical significance would vary according to buffer length and shape.

2. Methods

2.1 Sample

For this analysis, we used a subsample of the Nurses' Health Study II (NHSII), a large ongoing prospective cohort study. The NHSII cohort was initiated in 1989 and included 116,686 female registered nurses aged 25-42 years from 14 states (California, Connecticut, Indiana, Iowa, Kentucky, Massachusetts, Michigan, Missouri, New York, North Carolina, Ohio, Pennsylvania, South Carolina, and Texas). Response rates at each biennial questionnaire cycle have consistently been at or above 90%. All available residential addresses were geocoded to obtain latitude and longitude. The protocol for this study was

approved by the Institutional Review Board of Brigham and Women's Hospital and the Harvard School of Public Health. The return of the completed questionnaires was assumed to constitute implied consent to use the data in ongoing health research.

For this analysis, we selected participants from Texas and Pennsylvania, two states with diverse built environment typology (both contain very rural and very urban communities) that also have a large enrollment in the NHSII (12.3% of participants geocoded in 2009 lived in Pennsylvania, while 7.1% lived in Texas). We analyzed data from the year 2009, which was matched to our available data on businesses and streets. After excluding those without a home address geocoded at the street level ($n=2,038$) and those without a valid BMI measure ($n=3,460$), we had 11,178 participants from Pennsylvania and 6,255 participants from Texas available for analysis. All participants for this analysis were self-reported Caucasian women, with 2.3% identifying as Hispanic.

2.2 Built Environment Data

Street network data for intersection information came from TIGER 2010-based road network (Streetmap USA, ESRI). We excluded highways and on-ramps in the road network and then counted all three-way or greater intersections. Business data were obtained from the commercially available InfoUSA 2009 database from the Business Analyst Package in ArcGIS. InfoUSA is a spatial database on "points of interest", which includes grocery stores, restaurants, banks, hotels, hospitals, libraries, etc. InfoUSA maintains and adds to their database by referencing several sources including directory listings such as Yellow Pages; Securities and Exchange Commission (SEC) information; federal, state, and municipal government data; and information from the US Postal Service. InfoUSA compiles an address list of businesses from these sources and telephone verifications, and assigns latitude and longitude coordinates and a census geographic code to the business sites. Overall, 84.3% of the businesses are geocoded at the address level; 99.5% are assigned to a census block group (ESRI 2008). Businesses that cannot be assigned to a block group are assigned to a census tract or county. Our research team has performed a small validation study of over 400 facilities listed in the InfoUSA database in two US counties and found that 86% of the facilities were located in the field on the exact street segment or on an adjacent segment. These findings are comparable to three recent studies that assessed the validity of commercial facility databases using GIS techniques and field audits and found good to moderate percentage agreement and sensitivity for correctly identifying and locating existing facilities (Bader et al., 2010, Boone et al., 2008, Paquet et al., 2008). We did not restrict to any particular business type in this analysis and instead included all points of interest.

Using these data and Geographic Information Systems (GIS) software (ArcGIS 10), we created two buffer shapes: line-based network buffers and radial buffers. For each of these shapes, we created buffers of four scales: 400m, 800m, 1200m, and 1600m. For line-based network buffers, lines extended along the road network up to these distances. We then drew a 50m width around each line to create a polygon for the line-based network buffer. For radial buffers, distances represented the radius of the circular buffer around each residence. Within each buffer, we calculated business and intersection counts and densities. Figure 1

shows a hypothetical address with a 1200m line-based buffer and a 1200m radial buffer, along with InfoUSA business addresses layered on top. If located within the buffer, businesses were counted in the calculation for business count and density for each buffer type.

2.3 Health Outcomes

Energy balance outcomes for this analysis were body mass index (BMI) in kg/m^2 , based on self-reported height at the baseline 1989 questionnaire and self-reported weight on the 2009 questionnaire, as well as walking in metabolic equivalent hours per week (MET hrs/wk) based on responses to the 2009 physical activity questionnaire. Each questionnaire included questions on physical activity during the past year, with a question on the average time per week spent walking for exercise or walking to work in the past year. We multiplied the reported time spent walking weekly by its typical energy expenditure requirements expressed in MET hours per week score (Ainsworth et al., 1993). One MET, the energy expended while sitting quietly, is equivalent to 3.5 milliliters of oxygen uptake per kilogram of body weight per minute for a 70-kilogram adult. Walking was assigned a MET value corresponding to the reported pace: easy, casual, 2.5; normal, average, 3.0; brisk, 4.0; or very brisk/striding, 4.5 (Ainsworth et al., 1993). A validation study of 184 participants from a related study showed that self-reported weights were highly correlated with measured weights ($r = 0.96$; mean difference = 1.5 kg) (Willett et al., 1983). In a validation study of 147 nurses who completed the same physical activity questionnaire, as well as quarterly 7-day activity diaries, the Pearson correlation coefficient between the MET scores from the questionnaires and the average of the diaries was 0.46. After adjustment for within-person variation in the diaries, the de-attenuated correlation was 0.56 (Wolf et al., 1994).

2.4 Statistical Analysis

For these cross-sectional data, we conducted linear regression analyses; regressing the built environment variables on the energy balance data. The built environment variables were non-normal, and therefore we log-transformed the values prior to analysis. We ran separate analyses for each built environment measure and then compared measures based on a one-unit increase in the log-transformed value of the built environment variable. Analyses were adjusted for age (in years), smoking status (never, past, current <15 cigarettes/day, current 15 cigarettes/day), husband's education (<High School, High School, College, Grad School, Missing or Not Married) as a proxy for individual level socioeconomic status, and census tract median income (in \$) and home value (in \$) as a proxy for area level socioeconomic status. To test for effect modification by state, urban/rural status (based on the census tract Rural Urban Commuting Area codes from the US Census), and retirement status (from the questionnaire), interaction terms were added and stratified analyses were run.

In the data, 78% of census tracts had five or fewer participants; therefore, there was likely a low degree of correlation of data within a census tract. Because it was unlikely that we had violated the assumption of independence of observations necessary for linear regression, we felt multilevel level methods were unlikely to greatly influence results (Diez-Roux, 2000).

3. Results

Table 1 shows the characteristics of the participants included in this analysis. Participants had an average BMI of 28.2 and averaged 6.4 MET hrs/wk from walking. The average age was 53 years and 64.9% of participants never smoked. Over half of participants had a husband with at least a four year college education. Less than five percent of participants lived in rural census tracts or were retired. Figure 2 shows the range, median, and interquartile range of the log transformed built environment measures for the 400m and 1600m buffers. As expected, the larger buffers have higher counts for both businesses and intersections, and radial counts are higher than line-based counts for both measures. For density, these differences are not as large across different buffer sizes, but line-based densities are higher than radial densities due to the larger areas in radial buffers.

3.1 Built Environment Measures and Walking

Figure 3 shows the fully adjusted findings for each built environment measure and walking. Overall, there is a consistent positive relationship between all built environment measures and walking. For both intersection count and density, the 1200m buffer length for both line-based and radial buffers shows the largest effect size and reaches statistical significance (95% confidence intervals do not cross zero), while other buffer sizes show smaller effect sizes and do not reach statistical significance. For business count and density, line-based buffers above 400m showed statistically significant positive associations with walking, while radial buffers had consistent effect sizes across all buffer sizes but did not reach statistical significance. Results were similar after adjustment for state (Supplemental Figure 1). Stratified analyses are shown in Supplemental Figures 4, 6, and 8. While most effect sizes appeared larger for Pennsylvania compared to Texas for intersection measures, there were no statistically significant interactions by state for any of the measures. Analyses stratified by urban/rural status demonstrated larger effect sizes among participants living in rural census tracts; however, small numbers of rural participants led to wide confidence intervals. Some statistically significant interactions were observed by urban/rural status (intersection counts at 800m and 1200m line-based buffers, and for 400m and 800m radial buffers; intersection density at 400m line-based buffers, and for 400m and 800m radial buffers). Stratifying by retirement status demonstrated negative associations between built environment variables and walking among retired participants. The majority of interactions reached statistical significance, and relationships varied somewhat by buffer length and shape.

3.2 Built Environment Measures and BMI

Associations for each built environment measure and BMI are illustrated in Figure 4. Contrary to our *a priori* hypotheses, we observed a positive relationship between each built environment measure and BMI and most of these effects were statistically significant. For intersection counts, in both line-based and radial buffers, the strongest effect sizes were seen in the 400m buffers, and this effect diminished generally as buffer sizes got larger. For intersection density, effect sizes did not vary greatly by buffer size. Business count effect sizes were greatest for both buffer shapes at 400m and decreased with larger buffer size. For business density, 400m buffers had the smallest coefficient in the line-based buffer models,

while the radial buffers had the largest associations in the 400m buffers which decreased for each increase in buffer size. Results were consistent after adjustment for state (Supplemental Figure 2). Stratified analyses are shown in Supplemental Figures 5, 7, and 9. Effect sizes were larger for Texas compared to Pennsylvania across the majority of measures; however, only business density measured with 1600m line-based network buffers reached statistical significance. Relationships varied by buffer scale and shape. No consistent differences were observed by urban and rural status and no statistically significant interactions were observed. Although effect sizes were larger in retired compared to non-retired participants, trends were generally similar to unstratified analyses and only 400m and 800m line-based buffers for business count reached statistical significance.

4. Discussion

To illustrate an example of the uncertain geographic context problem (Kwan, 2012b) in a large dataset of adult women from diverse regions of the United States, we conducted analyses of the relationship between energy balance outcomes and measures of the built environment, calculated using line-based and radial buffers ranging from 400m to 1600m, including intersection and business densities and counts within these buffers. Results indicate that the scale and shape of buffers can have an impact on study results and may partly explain inconsistent findings from past studies of the built environment and energy balance. The majority of studies on the built environment and energy balance utilize only one buffer length within a study. For example, if we had chosen to look at intersection density and walking using only a 400m line-based buffer (Figure 3c), we would have drawn different conclusions than with a 1200m line-based buffer. Statistical inference is also affected by the buffer type choice, as seen in Figure 3d. Comparing confidence intervals for line-based and radial buffers, the line-based buffers greater than 400m reached statistical significance, while none of the radial buffers did. Additionally, results demonstrated a positive relationship between each built environment measure and BMI, with the majority of associations reaching statistical significance. Although this ran counter to our *a priori* hypotheses, it is possible that the attributes of the built environment that are positively correlated with walking may also be correlated with obesity. For example, a fast food restaurant would provide a viable destination nearby to walk to, but might also provide an abundance of inexpensive calories to intake (Reitzel et al., 2013, Li et al., 2009, Dubowitz et al., 2012). Further exploration of the business quality within each buffer is necessary to better understand the built environment and BMI results. Stratified analyses highlighted that differential relationships may exist according to factors such as retirement status. Overall, these findings underscore the issue of the uncertain geographic context problem, an emerging key concern for studies of associations between environment and behavior.

A few past studies have examined multiple buffer sizes to identify the most salient geographic context for energy balance. For instance, Boone-Heinonen et al. (2010) analyzed data about moderate and vigorous physical activity (MVPA) in 17,659 adolescents. The authors estimated the association of MVPA with physical activity facility counts and street connectivity measures looking at 1km, 3km, 5km, and 8.05km radial buffers. The study demonstrated that different buffer sizes and measures within those buffers held different relationships with MVPA, specifically physical activity facilities within 3km buffers and

intersection density within 1km buffers exhibited the most consistent associations with MVPA. Similar findings also have been observed in adult populations, including Berke et al. (2007), Zhang and Kukadia (2005), and Mitra and Builing (2012). In an extensive exploration of active travel and the built environment measured through radial buffers, grids, and administrative areas of varying sizes, results from Clark and Scott (2013) indicate that the choice of built environment metric changes the relationship between active travel and the built environment. The authors go on to suggest three principles for selecting the ideal scale to measure the built environment, including choosing a scale that is appropriate for the problem being investigated, such as policy relevant scales; selecting a scale related to the actual active travel distances; and using disaggregate data whenever possible. The results of these studies illustrate the uncertain geographic context problem and demonstrate how this problem may extend to a variety of overlapping units and activity spaces, impacting findings differently according to additional factors, such as age and gender.

Our analysis examines whether cross-sectional associations between measures of energy balance and the built environment vary by specific buffer sizes and shapes. The results presented should motivate a discussion of how to advance the field of the built environment and energy balance by illustrating the extent of the problem in a large cohort study of adult women. The uncertain geographic context problem highlights the need to better understand the relevant spatial context at which the built environment might influence energy balance. Simulations have demonstrated that the highest effect estimates and best model fit cannot alone identify the most relevant spatial context (Spielman and Yoo, 2009). Studies to empirically evaluate relevant spatial contexts provide some insight into the complexity of this issue. In a study of 909 adolescent girls of diverse racial and geographic backgrounds, Colabianchi et al. (2007) collected data on perceptions of easy walking distance and a convenient driving distance. The study suggests the use of a 1200m buffer to represent the walkable neighborhood for female adolescents, although perceptions of easy walking distance varied across race and BMI. Smith et al. (2010) interviewed 58 adult participants randomly selected from 10 areas of Stoke-on-Trent, England, and asked them to recall walking destinations and to draw their 'neighborhood walking area.' Neighborhood boundaries drawn by participants represented a mean of only 16% of area overlapping with 1600m radial buffers, with a range of 0.3% to 111%. When repeated using a network buffer, the same comparison resulted in a mean of 36% overlapping area with a range of 0.6 to 245%. In this adult population, perception of the neighborhood area does not appear to reflect the commonly used definitions of spatial context used in the recent built environment and health literature. These studies demonstrate the potential for misclassification when using the buffer technique to define relevant spatial contexts due to the uncertain geographic context problem. Additionally, factors such as race, socioeconomic status, car ownership, access to transit, and BMI could play a role in determining an individual's most relevant spatial context.

Moving beyond residence-based spatial units, novel approaches, such as using global positioning systems (GPS) data, may be necessary to understand activity space, or the relevant area in which an individual spends the majority of his/her time (Boruff et al., 2012, Zenk et al., 2011). For instance, Zenk et al. (2011) gave 120 adult residents of Detroit GPS devices and followed their movements for up to seven days. When comparing activity

spaces to half-mile (~800m) buffers based on the census block centroid, the authors found that most participants spent time in a broader space than their buffer, and that those activity spaces differed from buffers in features such as fast food outlet and supermarket density, as well as park land use. Data demonstrated some evidence that environmental features of the activity space were related to diet but were not related to the buffer-related measures. Another example of this is the analysis by Hurvitz and Moudon (2012), where the authors collected GPS data on 41 subjects in the Seattle area. Characteristics for 3.8 million points were measured using GIS data representing spatially continuous values of local built environment variables. Participants spent about 48.6% of their time near their home (<833m of home address based on a radial buffer) and 45.6% of their time >1,666m from their home address. Additionally, built environment values were significantly different for more than 90% of variables across subjects ($p<0.001$) comparing <833m to >1,666m areas. Finally, Boruff et al. (2012) created alternative buffers by combining objective GPS walking data with land use data and compared these alternative buffers to radial and line-based network buffers using data on older adults in Perth, Australia. Results indicated few significant relationships between the different built environment measures and walking for either leisure or transport purposes, although the model fit statistics indicated that land-use exposure for the alternative land-use based buffers provided a better fit for walking than the radial or network based buffers. These studies demonstrate that residence-based measures of the built environment may be insufficient, and underscore the need for innovative methods to better understand relevant contexts for built environment and health research.

The current study has a number of limitations. In light of the aforementioned studies that focus on GPS-based methods of defining the built environment, our focus on the area around a home residence may not be the most appropriate area to measure to understand built environment and energy balance relationships (Boruff et al., 2012, Zenk et al., 2011, Hurvitz and Moudon, 2012). The study population includes only older white women from Texas or Pennsylvania, and effect sizes observed might differ in other populations. However, the specific effect sizes are not the focus of this analysis and the intention is to demonstrate that choices of buffer length and shape can impact the interpretation of findings. As noted above and in other studies (Spielman and Yoo, 2009), numerous individual-level factors could impact the spatial context most influential to energy balance, including age, race, gender, and socioeconomic status. While the homogeneity of this population likely narrowed the influence that individual-level heterogeneity can have on the observed relationships, it simultaneously limited our ability to investigate the impact of these factors. We were able to explore individual heterogeneity by retirement status, which did have an effect on observed associations.

This study is cross sectional, limiting the causal interpretation of any findings. But this analysis is meant to motivate a discussion about the effects of different methods used to define built environment metrics. Data on walking behavior were based on self-reported walking for exercise or walking to work combined, which are not linked as closely to the built environment as transportation walking alone (McCormack and Shiell, 2011). This underreporting would be consistent across buffer scale and shape, so would be unlikely to impact the observed differences in associations between buffers. However, different elements of the built environment may have varying influences on specific types of walking

behavior that we were unable to examine because of this broadly defined outcome. Finally, although InfoUSA data have been shown to be relatively accurate (Bader et al., 2010, Boone et al., 2008, Paquet et al., 2008), there could be some misclassification in geocoding of business data. Again, this misclassification would likely be consistent across buffer length and shape, and therefore would not significantly alter the main findings of this study.

This study is bolstered by a large sample size of participants from two large states with diverse built environment types. Participants were drawn from an ongoing prospective cohort with a high level of follow-up and validated measures on energy balance outcomes. The diverse range of buffer sizes and shapes, coupled with multiple built environment measures and energy balance outcomes, provide valuable information to evaluate comparisons of effect sizes across different metrics.

The uncertain geographic context problem remains a complex concern for built environment and energy balance research and should be considered more often when reviewing the existing literature. This study uses data from a large cohort study to demonstrate how choices of buffer scale and shape can influence observed associations. A better understanding of relevant contexts through which the built environment influences energy balance behaviors is necessary. Pioneering methods, such as the inclusion of GPS to create personally tailored measures of the activity space in analyses, would reduce the spatial and temporal uncertainty in the actual areas that exert the contextual influences under study. Reducing this uncertainty would likely improve exposure assessment and improve our understanding of the true relationship between the built environment and energy balance.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

Acknowledgments

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References

- Ainsworth BE, Haskell WL, Leon AS, Jacobs DR Jr, Montoye HJ, Sallis JF, Paffenbarger RS Jr. Compendium of physical activities: classification of energy costs of human physical activities. *Medicine and Science in Sports and Exercise*. 1993; 25:71–80. [PubMed: 8292105]
- Bader MD, Ailshire JA, Morenoff JD, House JS. Measurement of the local food environment: a comparison of existing data sources. *American Journal of Epidemiology*. 2010; 171:609–17. [PubMed: 20123688]
- Berke EM, Koepsell TD, Moudon AV, Hoskins RE, Larson EB. Association of the built environment with physical activity and obesity in older persons. *American Journal of Public Health*. 2007; 97:486–92. [PubMed: 17267713]
- Berrigan D, Pickle LW, Dill J. Associations between street connectivity and active transportation. *International Journal of Health Geographies*. 2010; 9:20.

- Boone-Heinonen J, Popkin BM, Song Y, Gordon-Larsen P. What neighborhood area captures built environment features related to adolescent physical activity? *Health & Place*. 2010; 16:1280–6. [PubMed: 20650673]
- Boone JE, Gordon-Larsen P, Stewart JD, Popkin BM. Validation of a CIS facilities database: quantification and implications of error. *Annals of Epidemiology*. 2008; 18:371–7. [PubMed: 18261922]
- Boruff BJ, Nathan A, Nijenstein S. Using GPS technology to (re)-examine operational definitions of ‘neighbourhood’ in place-based health research. *International Journal of Health Geographies*. 2012; 11:22.
- Clark A, Scott D. Understanding the impact of the modifiable areal unit problem on the Relationship between active travel and the built environment. *Urban Studies*. 2013; 50:1–16.
- Cockings S, Martin D. Zone design for environment and health studies using pre-aggregated data. *Social science & medicine*. 2005; 60:2729–42. [PubMed: 15820583]
- Colabianchi N, Dowda M, Pfeiffer KA, Porter DE, Almeida MJ, Pate RR. Towards an understanding of salient neighborhood boundaries: adolescent reports of an easy walking distance and convenient driving distance. *The International Journal of Behavioral Nutrition and Physical Activity*. 2007; 4:66. [PubMed: 18088416]
- Coogan PF, White LF, Adler TJ, Hathaway KM, Palmer JR, Rosenberg L. Prospective study of urban form and physical activity in the Black Women’s Health Study. *American Journal of Epidemiology*. 2009; 170:1105–17. [PubMed: 19808635]
- Coogan PF, White LF, Evans SR, Adler TJ, Hathaway KM, Palmer JR, Rosenberg L. Longitudinal assessment of urban form and weight gain in African-American women. *American Journal of Preventive Medicine*. 2011; 40:411–8. [PubMed: 21406274]
- Cutchin MP, Eschbach K, Mair CA, Ju H, Goodwin JS. The socio-spatial neighborhood estimation method: an approach to operationalizing the neighborhood concept. *Health & place*. 2011; 17:1113–21. [PubMed: 21684793]
- Diez-Roux AV. Multilevel Analysis in Public Health Research. *Annual review of public health*. 2000; 21:171–192.
- Diez Roux AV, Mair C. Neighborhoods and health. *Annals of the New York Academy of Sciences*. 2010; 1186:125–145. [PubMed: 20201871]
- Dubowitz T, Ghosh-Dastidar M, Eibner C, Slaughter ME, Fernandes M, Whitsel EA, Bird CE, Jewell A, Margolis KL, Li W, Michael YL, Shih RA, Manson JE, Escarce JJ. The Women’s Health Initiative: The food environment, neighborhood socioeconomic status, BMI, and blood pressure. *Obesity*. 2012; 20:862–71. [PubMed: 21660076]
- Ewing R, Brownson RC, Berrigan D. Relationship between urban sprawl and weight of United States youth. *American Journal of Preventive Medicine*. 2006; 31:464–74. [PubMed: 17169708]
- Feng J, Glass TA, Curriero FC, Stewart WF, Schwartz BS. The built environment and obesity: a systematic review of the epidemiologic evidence. *Health & Place*. 2010; 16:175–90. [PubMed: 19880341]
- Finkelstein EA, Trogdon JG, Cohen JW, Dietz W. Annual medical spending attributable to obesity: payer-and service-specific estimates. *Health Affairs*. 2009; 28:w822–31. [PubMed: 19635784]
- Flowerdew R. How serious is the modifiable areal unit problem for analysis of English census data? *Population Trends*. 2011:102–14. [PubMed: 21987016]
- Flowerdew R, Manley DJ, Sabel CE. Neighbourhood effects on health: does it matter where you draw the boundaries? *Social Science & Medicine*. 2008; 66:1241–55. [PubMed: 18177988]
- Forsyth A, Van Riper D, Larson N, Wall M, Neumark-Sztainer D. Creating a replicable, valid cross-platform buffering technique: the sausage network buffer for measuring food and physical activity built environments. *International Journal of Health Geographies*. 2012; 11:14.
- Foster K, Hipp J. Defining neighborhood boundaries for social measurement: Advancing social work research. *Social Work Research*. 2011; 35:25–35.
- Handy, S. Transportation Research Board & Institute of Medicine Does the Built Environment Influence Physical Activity? Examining the Evidence. Washington, DC: National Academies; 2005. Critical Assessment of the Literature on the Relationships Among Transportation, Land Use, and Physical Activity.

- Handy SL, Boarnet MG, Ewing R, Killingsworth RE. How the built environment affects physical activity: views from urban planning. *American journal of preventive medicine*. 2002; 23:64–73. [PubMed: 12133739]
- Haynes R, Daras K, Reading R, Jones A. Modifiable neighbourhood units, zone design and residents' perceptions. *Health & Place*. 2007; 13:812–25. [PubMed: 17369075]
- Hurvitz PM, Moudon AV. Home versus nonhome neighborhood: quantifying differences in exposure to the built environment. *American Journal of Preventive Medicine*. 2012; 42:411–7. [PubMed: 22424255]
- James P, Troped PJ, Hart JE, Joshu CE, Colditz GA, Brownson RC, Ewing R, Laden F. Urban sprawl, physical activity, and body mass index: Nurses' Health Study and Nurses' Health Study II. *American Journal of Public Health*. 2013; 103:369–75. [PubMed: 22698015]
- Jones AP, Van Sluijs EM, Ness AR, Haynes R, Riddoch CJ. Physical activity in children: does how we define neighbourhood matter? *Health & place*. 2010; 16:236–41. [PubMed: 19906555]
- Joshu CE, Boehmer TK, Brownson RC, Ewing R. Personal, neighbourhood and urban factors associated with obesity in the United States. *Journal of Epidemiology and Community Health*. 2008; 62:202–8. [PubMed: 18272734]
- Kwan M. How CIS can help address the uncertain geographic context problem in social science research. *Annals of CIS*. 2012a; 18:245–255.
- Kwan M. The uncertain geographic context problem. *Annals of the Association of American Geographers*. 2012b; 102:958–968.
- Leal C, Chaix B. The influence of geographic life environments on cardiometabolic risk factors: a systematic review, a methodological assessment and a research agenda. *Obesity Reviews*. 2011; 12:217–30. [PubMed: 20202135]
- Lee IM, Shiroma EJ, Lobelo F, Puska P, Blair SN, Katzmarzyk PT. Effect of physical inactivity on major non-communicable diseases worldwide: an analysis of burden of disease and life expectancy. *Lancet*. 2012; 380:219–29. [PubMed: 22818936]
- Li F, Harmer P, Cardinal BJ, Bosworth M, Johnson-Shelton D. Obesity and the built environment: does the density of neighborhood fast-food outlets matter? *American Journal of Health Promotion*. 2009; 23:203–9. [PubMed: 19149426]
- Lopez RP. Neighborhood risk factors for obesity. *Obesity*. 2007; 15:2111–9. [PubMed: 17712130]
- Mccormack GR, Shiell A. In search of causality: a systematic review of the relationship between the built environment and physical activity among adults. *The International Journal of Behavioral Nutrition and Physical Activity*. 2011; 8:125. [PubMed: 22077952]
- Mitra R, Buliung R. Built environment correlates of active school transportation: neighborhood and the modifiable areal unit problem. *Journal of Transport Geography*. 2012; 20:51–61.
- Moos, R. The human context: environmental determinants of behavior. New York: John Wiley & Sons; 1976.
- Mujahid MS, Diez Roux AV, Shen M, Gowda D, Sanchez B, Shea S, Jacobs DR Jr, Jackson SA. Relation between neighborhood environments and obesity in the Multi-Ethnic Study of Atherosclerosis. *American Journal of Epidemiology*. 2008; 167:1349–57. [PubMed: 18367469]
- Nelson MC, Gordon-Larsen P, Song Y, Popkin BM. Built and social environments associations with adolescent overweight and activity. *American Journal of Preventive Medicine*. 2006; 31:109–17. [PubMed: 16829327]
- Oliver LN, Schuurman N, Hall AW. Comparing circular and network buffers to examine the influence of land use on walking for leisure and errands. *International Journal of Health Geographies*. 2007; 6:41.
- Paquet C, Daniel M, Kestens Y, Leger K, Gauvin L. Field validation of listings of food stores and commercial physical activity establishments from secondary data. *The International Journal of Behavioral Nutrition and Physical Activity*. 2008; 5:58. [PubMed: 19000319]
- Parenteau MP, Sawada MC. The modifiable areal unit problem (MAUP) in the relationship between exposure to NO₂ and respiratory health. *International journal of health geographies*. 2011; 10:58.
- Reitzel LR, Regan SD, Nguyen N, Cromley EK, Strong LL, Wetter DW, McNeill LH. Density and proximity of fast food restaurants and body mass index among African Americans. *American Journal of Public Health*. 2013

- Rundle A, Diez Roux AV, Free LM, Miller D, Neckerman KM, Weiss CC. The urban built environment and obesity in New York City: a multilevel analysis. *American Journal of Health Promotion*. 2007; 21:326–34. [PubMed: 17465178]
- Rutt CD, Coleman KJ. Examining the relationships among built environment, physical activity, and body mass index in El Paso, TX. *Preventive Medicine*. 2005; 40:831–41. [PubMed: 15850885]
- Sallis JF, Cervero RB, Ascher W, Henderson KA, Kraft MK, Kerr J. An ecological approach to creating active living communities. *Annual Review of Public Health*. 2006; 27:297–322.
- Sallis JF, Floyd MF, Rodriguez DA, Saelens BE. Role of built environments in physical activity, obesity, and cardiovascular disease. *Circulation*. 2012; 125:729–37. [PubMed: 22311885]
- Sallis, JF.; Owen, N. Ecological models. In: Glanz, K.; Lewis, FM.; Rimmer, BK., editors. *Health behavior and health education: theory, research and practice*. San Francisco: Jossey-Bass; 1997.
- Santos SM, Chor D, Werneck GL. Demarcation of local neighborhoods to study relations between contextual factors and health. *International journal of health geographies*. 2010; 9:34.
- Sherwood NE, Jeffery RW. The behavioral determinants of exercise: implications for physical activity interventions. *Annual review of nutrition*. 2000; 20:21–44.
- Smith, Gr; Gidlow, C.; Davey, R.; C, F. What is my walking neighbourhood? A pilot study of English adults' definitions of their local walking neighbourhoods. *The International Journal of Behavioral Nutrition and Physical Activity*. 2010 May 6.:34. [PubMed: 20459636]
- Spielman SE, Yoo EH. The spatial dimensions of neighborhood effects. *Social science & medicine*. 2009; 68:1098–105. [PubMed: 19167802]
- Troped PJ, Starnes HA, Puett RC, Tamura K, Cromley EK, James P, Ben-Joseph E, Melly SJ, Laden F. Relationships between the built environment and walking and weight status among older women in three U.S. states. *Journal of Aging and Physical Activity*. 2013
- Willett W, Stampfer MJ, Bain C, Lipnick R, Speizer FE, Rosner B, Cramer D, Hennekens CH. Cigarette smoking, relative weight, and menopause. *American Journal of Epidemiology*. 1983; 117:651–8. [PubMed: 6859020]
- Wolf AM, Hunter DJ, Colditz GA, Manson JE, Stampfer MJ, Corsano KA, Rosner B, Kriska A, Willett WC. Reproducibility and validity of a self-administered physical activity questionnaire. *International Journal of Epidemiology*. 1994; 23:991–9. [PubMed: 7860180]
- Zenk SN, Schulz AJ, Matthews SA, Odoms-Young A, Wilbur J, Wegrzyn L, Gibbs K, Braunschweig C, Stokes C. Activity space environment and dietary and physical activity behaviors: a pilot study. *Health & Place*. 2011; 17:1150–61. [PubMed: 21696995]
- Zhang M, Kukadia N. Metrics of Urban Form and the Modifiable Areal Unit Problem. *Transportation Research Record: Journal of the Transportation Research Board*. 2005; 1902:71–79.

Highlights

1. Findings in research on the built environment and energy balance are inconsistent.
2. Uncertainty on the context relevant to energy balance drives this inconsistency.
3. We constructed built environment measures of varying buffer sizes and shapes.
4. We modeled the effect of these measures on self reported walking and BMI.
5. Effect sizes and statistical significance varied by buffer size and shape.

Figure 1.
Example of a Radial Buffer and Line-based Buffer with Business Addresses

Figure 2.
Distribution of Log-transformed Built Environment Measures. Boxes represent the interquartile range and whiskers represent range of values

Figure 3. Coefficients and 95% Confidence Intervals for Effect of Built Environment Measures on Walking. Triangles represent line based buffers and circles are radial buffers.

Figure 4.

Coefficients and 95% Confidence Intervals for Effect of Built Environment Measures on BMI. Triangles represent line based buffers and circles are radial buffers.

Note: Y-axis varies across panels

Table 1

Population Characteristics

	Total (n=17,486)	PA (n=11,178)	TX (n=6,308)
Variable	Mean±SD or N (%)		
BMI (kg/m ²)	28.2±6.7	28.1±6.6	28.2±6.8
Walking METs (hrs/wk) *	6.4±8.8	6.7±9.1	5.7±8.3
Age	54.8±4.4	54.9±4.4	54.6±4.6
Smoking Status			
Never	11,350 (64.9)	7,129 (63.8)	4,221 (67.0)
Past	4,705 (26.9)	3,132 (28.0)	1,573 (24.9)
Current 1-14 / day	743 (4.3)	485 (4.3)	258 (4.1)
Current 15+ / day	586 (3.4)	376 (3.4)	210 (3.3)
Missing	102 (0.6)	56 (0.5)	46 (0.7)
Husband's Education			
Less than High School	120 (0.7)	74 (0.7)	46 (0.7)
High School	2,770 (15.8)	2,155 (19.3)	615 (9.8)
Two Year College	2,758 (15.8)	1,750 (15.7)	1,008 (16.0)
Four Year College	4,617 (26.4)	2,802 (25.1)	1,815 (28.8)
Graduate School	4,266 (24.4)	2,643 (23.6)	1,623 (25.7)
Missing or Not Married	2,955 (16.9)	1,754 (15.7)	1,201 (19.0)
Census Tract Median Income	\$63,493±\$23,541	\$61,197±\$21,035	\$67,564±\$26,951
Census Tract Median Household Value	\$129,138±\$66,908	\$129,473±\$61,885	\$128,541±\$74,989
Urban / Rural Status			
Urban	16,862 (96.4)	10,677 (95.5)	6,185 (98.1)
Rural	624 (3.6)	501 (4.5)	123 (1.95)
Retirement Status			
Not Retired	16,650 (95.2)	10,645 (95.2)	6,005 (95.2)
Retired	836 (4.8)	533 (4.8)	303 (4.8)

* N=13,715