Published in final edited form as:

Health Place. 2018 January ; 49: 30–38. doi:10.1016/j.healthplace.2017.11.003.

Comparing objective measures of the built environment in their associations with youth physical activity and sedentary behavior across heterogeneous geographies

Melissa N. Poulsen, PhD, MPH^{a,b}, Emily A. Knapp, MHS^c, Annemarie G. Hirsch, PhD, MPH^b, Lisa Bailey-Davis, DEd, RD^b, Jonathan Pollak, MPP^a, and Brian S. Schwartz, MD, MS^{a,b,c,d}

^aDepartment of Environmental Health and Engineering, Johns Hopkins Bloomberg School of Public Health, 615 N. Wolfe Street, Baltimore, MD 21205, USA

^bDepartment of Epidemiology and Health Services Research, Geisinger Health System, 100 North Academy Avenue, MC 44-00, Danville, PA 17822, USA

^cDepartment of Epidemiology, Johns Hopkins Bloomberg School of Public Health, 615 N. Wolfe Street, Baltimore, MD 21205, USA

^dDepartment of Medicine, Johns Hopkins School of Medicine, 733 N. Broadway, Baltimore, MD 21205, USA

INTRODUCTION

Through its influence on diet, physical activity (PA), and sedentary behavior, the built environment is hypothesized to be a key determinant of the obesity epidemic (Carroll-Scott et al., 2013; Garfinkel-Castro et al., 2017; Sallis and Glanz, 2009; Swinburn et al., 1999; Swinburn et al., 2011). Understanding how environmental attributes promote or impede obesity-related behaviors can help guide policies and interventions to design healthier communities. Considering the persistence of adiposity and obesity-related risk behaviors from childhood into adulthood (Howe et al., 2015), such efforts may have long-term implications on health.

Environmental features that promote or hinder safe recreation and active transit can influence PA and sedentary behavior (Bringolf-Isler et al., 2014; Popkin et al., 2005; Stierlin et al., 2015; Timperio et al., 2015). As evidenced by “review of reviews” articles (de Vet et al., 2011; Ding and Gebel, 2012), a substantial body of literature links PA to attributes of the built environment. The built environment is also considered a key influence on sedentary behavior, although fewer studies have examined this relationship (Chastin et al., 2016; Stierlin et al., 2015). This combined body of research reveals that few place-level features

Address correspondence to: Melissa N. Poulsen, Johns Hopkins Bloomberg School of Public Health, Department of Environmental Health and Engineering, 615 N. Wolfe Street / Room W7041, Baltimore, MD 21205, USA, [mpoulse1@jhu.edu].

Publisher's Disclaimer: This is a PDF file of an unedited manuscript that has been accepted for publication. As a service to our customers we are providing this early version of the manuscript. The manuscript will undergo copyediting, typesetting, and review of the resulting proof before it is published in its final citable form. Please note that during the production process errors may be discovered which could affect the content, and all legal disclaimers that apply to the journal pertain.

Conflicts of interest: The authors have no conflicts of interest to disclose.

(e.g., access to parks, neighborhood aesthetics) are consistently associated with PA or sedentary behavior (Ding et al., 2011; Stierlin et al., 2015; Timperio et al., 2015), which may in part reflect the heterogeneity in how studies characterize, measure, and model the built environment (Feng et al., 2010). For example, the influence of the built environment—and thus the effect of specific environmental attributes—varies between different domains of PA (Brownson et al., 2009; Ding et al., 2011; Giles-Corti et al., 2005). Recreational PA may be most influenced by the *fitness and recreation environment* (access to parks, playgrounds, and recreation facilities), while the *utilitarian PA environment* (walkability and cycling infrastructure of an area) likely affects active transport (American Academy of Pediatrics, 2009; Sallis et al., 2012). The multidimensionality of the built environment presents an additional research challenge, requiring measures that capture multiple elements at once, such as incorporating land use mix, street connectivity, residential density, and retail intensity to measure the walkability of neighborhoods (Sallis et al., 2012). Measuring individual environmental attributes in isolation from the broader context ignores the cumulative effects that may be required to affect behavior, yet the complexity of large composite measures has impeded widespread use (Brownson et al., 2009; Sallis et al., 2012).

Mode of measurement has also been shown to influence the consistency of associations between neighborhood environments and youth PA (de Vet et al., 2011; Ding et al., 2011). In particular, objectively measured environmental attributes appear more consistently related to youth PA than self-reported (perceived) attributes, likely due to less measurement error (Ding et al., 2011). Less is known about how various modes of objectively measuring the PA environment compare in their associations with youth PA or sedentary behavior. Researchers have used one of two main measurement modes to objectively characterize aspects of the built environment that are theoretically linked to health outcomes: 1) archival datasets that contain a spatial reference (usually analyzed with GIS); or 2) observational measures derived through community audits (Bader et al., 2010; Brownson et al., 2009). Archival data such as census data and commercial databases can provide an expedient and accessible source of information, and is particularly useful for geographically expansive and dispersed studies since such datasets usually provide complete geographic coverage (Bader et al., 2010; Brownson et al., 2009). However, archival data lacks contextual information such as the quality and conditions of local infrastructure (Brownson et al., 2009; Giles-Corti et al., 2005; Schaefer-McDaniel et al., 2010). To overcome this limitation, researchers have turned to direct observation, or audit, of communities, which entails a trained observer using a tailored instrument to gather information on-site about social and environmental conditions. While direct observation provides greater context than secondary data, it only measures neighborhood features that are visible and readily identifiable (Schaefer-McDaniel et al., 2010). Because it requires raters to travel to and observe neighborhoods, direct observation is often more burdensome and time-consuming than the use of archival data, with more limited geographic coverage (Bader et al., 2010; Brownson et al., 2009).

While challenges abound in validly measuring elements of the built environment that influence youth PA and sedentary behavior, this area of research remains a priority, as environmental interventions to increase PA have the potential for lasting impacts on communities (Giles-Corti et al., 2005). Studies examining heterogeneous geographies are of particular relevance, since environmental correlates of childhood obesity differ by geography

(Schwartz et al., 2011) and a lack of spatial variation in study design limits researchers ability to identify influential environmental features (Feng et al., 2010; Giles-Corti et al., 2005). With few exceptions (e.g., Knapp et al., 2017), much of the research characterizing obesogenic environments has been conducted in homogenous geographies, particularly urban areas (Feng et al., 2010; Hansen et al., 2015).

We sought to overcome several limitations of past studies of the PA environment, comparing two objective measurement strategies in their associations with domain-specific PA and sedentary behaviors among youth in heterogeneous geographies of Pennsylvania. The first measurement strategy involved the use of spatially referenced archival data, which we subjected to formal, hypothesis-driven data reduction via confirmatory factor analysis (CFA). The second involved direct observation using a community audit tool. The two strategies represented different measurement modes that captured multidimensional elements of PA environments and were specifically created to characterize the diverse geographies of our study region. Given the lack of an established “gold standard” that could be used as a comparison, we evaluated the measures from each strategy in terms of their associations with youth PA and sedentary behaviors. The assumption underlying this approach was that the built environment influences specific behaviors in predictable ways; therefore valid measures of the PA environment should be associated with PA and sedentary behaviors.

METHODS

This study was conducted under phase 2 of the project “Understanding Obesity from Epigenetics to Communities,” a collaboration between Johns Hopkins Bloomberg School of Public Health and Geisinger.

Study Population

Using electronic health record data from Geisinger, an integrated healthcare system serving a 45-county region of central and northeastern Pennsylvania, we recruited youth ages 10-15 years and their parents from 28 communities. Communities were geographically distributed across Geisinger’s service area. Communities were selected with an aim of collecting data from areas with low and high average body mass indexes among youth and representing a range of obesogenic and obesoprotective environments. Communities with the highest and lowest quintiles of obesogenic environments were selected based on three features associated with obesity risk: physical activity establishment diversity, population density, and community socioeconomic deprivation (Bailey-Davis et al., 2017; Schwartz et al., 2011). Further details on community selection were previously described (Bailey-Davis et al., 2017).

To define community boundaries, we capitalized on a mixed definition of place that incorporated minor civil divisions (townships, boroughs [the administrative unit of towns], and cities) and partitioned cities into census tracts. This allowed us to define sociologically valid representations of non-urban areas while dividing more densely populated cities into smaller, more relevant spatial resolutions. Study communities comprised 11 townships, 9 boroughs, and 8 city census tracts. Past research from the Geisinger catchment area using the

mixed definition of place showed that mean population density and land use mix was lowest in townships, higher in boroughs, and highest in cities (Schwartz et al., 2011), reflecting the rural-to-urban gradient in these community types. Community socioeconomic deprivation followed a parallel trend, with townships less deprived than boroughs and cities.

Data Collection

Behavioral data and demographic covariates were obtained through self-administered questionnaires completed separately by parents and youth (N = 434 dyads) during home visits conducted in 2013–2014. Recruitment details were previously reported (Bailey-Davis et al., 2017). Questionnaires included items related to youth PA and other obesity-related topics (Bailey-Davis et al., 2017). Items used to assess PA and sedentary behavior came from the Active Where? parent/adolescent survey.

Direct observation of the social and physical attributes of study communities was conducted in 2013–2015 by a single trained auditor using the Community Audit of Social, Civil, and Activity Domains in Diverse Environments (CASCADDE) tool. CASCADDE was developed to characterize multidimensional obesity-related environmental features across diverse geographical settings (Knapp et al., 2017). The iPad-based tool includes seven indices, four of which pertain to the PA environment, with items that maximize directly observable features. The full instrument is available in a previous publication (Knapp et al., 2017). The auditor observed a radius of 0.1 miles around fixed points, which were midpoints of selected roads. Twenty points were randomly sampled per community; 15 points were found to provide stable means. Correlations with secondary data such as Walk Score, and with community BMI percentiles, supported the construct validity of CASCADDE indices (Knapp et al., 2017).

In a prior analysis (manuscript in preparation), we conducted a CFA to develop a theory-based, formal model for measuring underlying, or latent, constructs that characterize the obesogenic environment. Based on theory and prior literature we selected an initial pool of candidate indicators drawn from archival data from the Geisinger catchment area. After transforming skewed variables and dropping highly correlated indicators, we estimated the CFA model, using progressive model refinement to achieve an acceptable fit. Once the optimal model was identified, we generated factor scores for each of four constructs. Factor scores varied by place type and population density, providing some evidence of construct validity (manuscript in preparation). The final model included two constructs, or domains, relevant to the PA environment: the fitness and recreation environment and utilitarian PA environment. These domains included ten total PA and land use indicators related to PA establishments (obtained from InfoUSA and Dun and Bradstreet), social characteristics (U.S. census), and land use patterns as defined by street networks (Pennsylvania Department of Transportation). The CFA was conducted using data from 2000; for this study we updated factor scores using 2010 data (the most recently available data), z-transforming and summing the same indicators. The 2000 and 2010 factor scores were highly correlated (Pearson's r 's: fitness and recreation factor = 0.75; utilitarian PA environment factor = 0.81).

Behavioral Outcomes

We evaluated three behavioral outcomes, matched to relevant domains of the PA environment. For measures of the utilitarian PA environment we evaluated active transport to school; for measures of the fitness and recreation environment we evaluated associations with organized out-of-school PA; and for both domains we evaluated sedentary behavior. For outcomes asked of both parents and youth, we averaged the two responses, since combining multiple reports of youth PA can yield more complete estimates of PA than a single measure (Chaumeton et al., 2011). Intra-class correlation coefficients for items ranged from 0.35 to 0.78 (Joe et al.).

Active transport to school (dichotomous) was based on the number of days per week youth reported walking or biking to or from school. Since most youth reported no active transport, we dichotomized the variable as ever vs. never.

Organized out-of-school PA (categorical) was defined by the mean of parent and youth report of the number of hours per week the youth engaged in organized team sports and activity training classes or lessons outside of school, averaged over four seasons. Parent and child report was moderately correlated (Spearman's $\rho = 0.68$). Due to a skewed distribution that was not improved with log transformation, the variable was categorized as 0 hours, 1 to 2.5 hours, > 2.5 to < 5.5 hours, and ≥ 5.5 hours.

Sedentary behavior (continuous) was evaluated using an index of nine sedentary activities: watching TV, playing video games, playing active video games, using internet for leisure, sitting listening to music, sitting talking on phone/texting, sitting "hanging out" with friends/family, and reading not for school. We summed the total hours per week youth spent engaged in these activities during the school year, averaging parent and youth responses, and divided total hours by the number of items reported to obtain average hours per sedentary behavior reported per week. Parent and child report was moderately correlated (Spearman's $\rho = 0.50$).

Measures of the Physical Activity Environment

We assessed the two PA environment domains using two measurement methods: 1) direct observation (DO) using CASCADDE; and 2) archival data using factor scores from the CFA (Table 1). To evaluate the utilitarian PA environment, we used three CASCADDE indices (barriers to physical activity [DO-barriers], environmental features that promote safety [DO-safety], commercial and civic intensity [DO-commercialization]) and one CFA factor (utilitarian physical activity favorability [CFA-utilitarian]). To evaluate the fitness and recreation environment, we used one CASCADDE index (physical activity promoting features [DO-recreation]) and one CFA factor (fitness and recreational assets [CFA-recreation]).

Statistical Analysis

The goal of the analysis was to compare two strategies for objectively measuring the PA environment (direct observation and spatially referenced archival data subjected to CFA) in heterogeneous geographies in their associations with youth PA and sedentary behavior. To

assess associations between environmental measures and behavioral outcomes, we conducted multivariable regression analyses, using logistic regression to evaluate active transport to school, linear regression to evaluate sedentary behavior, and multinomial logistic regression to evaluate hours of organized out-of-school PA. To assist with the interpretation of linear regression results, we rescaled each environmental measure by the difference in the interquartile range (IQR) and re-ran regression models. The resulting coefficients represented the differences in sedentary behavior comparing youth in communities in the 75th percentile of the environmental measures versus those in the 25th percentile (i.e., compares youth with a typical “high” value of an environmental measure with youth with a typical “low” value). Since distributions of environmental measures differed markedly comparing townships with boroughs and city census tracts, we stratified all models by community type (township versus borough/city census tract). Non-stratified models would have combined non-overlapping data, leading to regression extrapolation. Stratification also partially addressed the clustering of study participants within communities (Knapp et al., 2017). To further account for clustering by place, we included a random intercept for community in logistic and linear regression models, and used robust standard errors in multinomial logistic regression models. The robust estimator displayed variable small-sample performance, sometimes providing more precise standard errors than standard models; therefore, we present the more conservative inference and confidence interval for multinomial models, whether derived from the robust or standard estimator. All models were adjusted for youth age (continuous), youth sex, youth race/ethnicity (white, black, Hispanic/other), and youth history of Medical Assistance (Medicaid or the Children’s Health Insurance Plan; yes versus no; a proxy for low family socioeconomic status (Schwartz et al., 2014)). We did not correct for multiple testing, preferring to allow readers to interpret results rather than arbitrarily censoring findings. We assessed relations between behavioral outcomes using ANOVA (organized out-of-school PA and sedentary behavior), a chi-square test (organized out-of-school PA and active transport to school) and a t-test (active transport to school and sedentary behavior). From the original 434 parent-youth dyads, we excluded nine with missing information from the community audit ($N = 425$). An additional 11 dyads were missing information on active transport to school, thus sample sizes vary by model. Results are reported as odds ratios (OR), beta coefficients (β), or relative risk ratios with confidence intervals [CI] and were considered statistically significant at two-tailed $p < 0.05$ and borderline significant at $p < 0.10$. All analyses were performed using Stata version 14.0 (StataCorp LP, College Station, TX).

RESULTS

Differences in Youth Characteristics and Environmental Measures by Community Type

The 425 youth in the study had a median age of 13 years and were primarily non-Hispanic white (Table 2). A greater proportion of youth residing in boroughs and cities received Medical Assistance as compared to township youth. Youth in townships—a community type that ranges from rural to suburban—also differed on study outcomes, with fewer reporting active transport to school, a lower median sedentary behavior, and a greater proportion participating in at least one hour of organized out-of-school PA. Distributions of the

environmental measures also differed by community type: townships generally had lower scores for the fitness and recreation environment and utilitarian PA environment.

Relationships between Youth PA and Sedentary Behaviors

Youth who participated in active transport to school had higher mean sedentary behavior (8.86 versus 7.12, $t = -4.75$, $p\text{-value} < 0.001$). Mean sedentary behavior was negatively related to the number of hours of organized out-of-school PA (sedentary behavior: 0 hours = 8.32, 1 to 2.5 hours = 7.32, > 2.5 to < 5.5 hours = 7.85, 5.5 hours = 6.67; $f = 4.36$, $p\text{-value} = 0.005$). There was no relation between organized out-of-school PA and active transport to school (chi-square = 2.16, $p\text{-value} = 0.54$).

Correlations between Environmental Measures

The two objective measures of the fitness and recreation environment (DO-recreation and CFA-recreation) were moderately positively correlated (Spearman's $\rho = 0.41$; Figure 1). When stratified by community type, the correlation between the two measures remained positive in townships (0.47) and boroughs (0.48), but was negative in cities (-0.46).

The direct observation and CFA-derived measures of the utilitarian PA environment were strongly correlated when assessed among all community types; however, when stratified by community type, correlations weakened substantially (Table 3; Figure 2).

Direct Observation and CFA-Derived Measures Associated with Active Transport

In multivariable regression analysis, the odds of active transport were significantly lower in communities with greater DO-barriers scores in boroughs/cities (OR [CI], $p\text{-value}$) (0.16 [0.04, 0.58], 0.005) (Figure 3). Thus, for each one-point increase in a borough or city's DO-barriers score, youth were 84% less likely to walk or bike to school. In townships, youth had 2.60 and 2.38 higher odds of active transport for each one-point increase in DO-commercialization and CFA-utilitarian scores, respectively (DO-commercialization: 2.60 [1.00, 6.77], 0.05; CFA-utilitarian: 2.38 [0.85, 6.66], 0.10). DO-safety was not associated with active transport to school.

Direct Observation Measures Associated with Sedentary Behavior

Among youth in boroughs/cities, sedentary behavior was lower in communities with higher DO-recreation and DO-safety scores (beta [CI], $p\text{-value}$) (DO-recreation: -0.34 [-0.70 , 0.02], 0.07; DO-safety: -0.37 [-0.62 , -0.11], 0.005) (Figure 4). Rescaling by the IQR showed that youth living in boroughs/cities in the 75th percentile of DO-recreation reported 0.90 fewer mean hours per week of sedentary behavior than did youth in the 25th percentile, and 1.38 fewer mean hours per week when comparing youth in the 75th and 25th percentiles of DO-safety. In townships, DO-commercialization was positively associated with sedentary behavior (0.72 [0.14, 1.29], 0.02). Rescaled by IQR, youth living in townships in the 75th percentile of DO-commercialization reported 1.60 fewer mean hours per week of sedentary behavior than did youth in the 25th percentile. CFA-recreation, DO-barriers, and CFA-utilitarian were not associated with sedentary behavior.

CFA-Derived Measure Associated with Out-of-School PA

There was no relation between DO-recreation and the number of hours that youth engaged in organized out-of-school PA (results not shown). Among youth in boroughs/cities, CFA-recreation was positively associated with the highest level of organized out-of-school PA (relative risk ratio [CI], p-value) (0 hours = reference; 1 to 2.5 hours: 1.07 [0.95, 1.22], 0.26; > 2.5 to < 5.5 hours: 0.99 [0.88, 1.11], 0.84; 5.5 hours: 1.15 [1.01, 1.31], 0.03). Thus, for each one-point increase in CFA-recreation, youth had 1.15 higher odds of participating in 5.5 or more hours (versus no hours) of out-of-school PA.

Summary of Multivariable Regression Results

Overall, direct observation measures were more robust in capturing differences in active transport and sedentary behavior as compared to CFA-derived measures, and measures of the fitness and recreation environment were not strongly related to organized out-of-school PA (Table 4 summarizes all observed relations).

DISCUSSION

This study compared two strategies for objective measurement of the PA environment—direct observation and spatially referenced archival data subjected to CFA—each of which offered a number of strengths. As composite measures, both captured multidimensional elements of the built environment, overcoming limitations of measuring individual environmental attributes in isolation from one another. CASCADDE, the community audit tool, incorporated contextual information regarding the conditions of local infrastructure and was tailored to capture differences across the diverse geographies of our study area. Constructing archival data measures from CFA results provided a theoretically rigorous basis for selecting indicators based on latent constructs. Despite these strengths, neither the direct observation nor CFA-derived measures showed consistent associations with youth PA and sedentary behavior across community types, although direct observations measures performed better.

The inconsistencies in our findings in part reflect the ongoing challenge of measuring environmental attributes that influence youth behaviors across heterogeneous settings. Understanding the effect of community type on behavior requires evaluation of diverse places with a range of measurements of interest so as to obtain sufficient variation in environmental measures. Yet most studies of the built environment and PA have been conducted in homogenous settings (Feng et al., 2010). One challenge in evaluating communities with diversity in street networks, commercial activity, residential zoning, population density, and design features, for example, is that key measures may not have overlapping distributions, as reflected in the current study. To overcome this challenge, we stratified our analyses by community type, which allowed for observation of community-level differences in the associations between environmental measures and behavior, but resulted in smaller sample sizes, limiting our power to detect associations. The larger project under which this study was conducted was designed to separate person from place by sampling from obesogenic to obesoprotective communities, as described in the Methods. It was not, however, powered for stratification by community type, as we only learned the

importance of community type as a determining factor of community features—and thus the necessity of stratification—after data analysis. For this reason, our findings should be considered somewhat preliminary.

Correlations and scatterplots of the evaluated environmental measures demonstrated that although direct observation measures were reasonably well correlated with comparable CFA-derived measures when examined across all community types, these findings are misleading. When stratified by community type, correlations weakened or changed direction. This suggests that although the two measurement strategies consistently captured macro-level differences in the built environment that differentiate community types (e.g., urban versus rural), when examining communities of the same type, the two strategies did not measure interrelated attributes. This is perhaps less surprising for measures of the utilitarian PA environment, since the three direct observation measures captured substantially different features of the environment than did the CFA-derived measure, and more so for the fitness and recreation environment measures, which had substantial overlap. These findings confirm the important influence of community type in evaluations of the PA environment.

Overall, direct observation measures appeared to perform better than CFA-derived measures in capturing environmental differences that may influence youth behavior. Various direct observation measures were associated (or showed borderline associations) with sedentary behavior and active transport to school, but not organized out-of-school PA. Of the CFA-derived measures, only CFA-recreation was significantly associated with a behavioral outcome (organized out-of-school PA in boroughs/cities), and this relation was limited to the highest level of PA. More robust findings for direct observation measures indicate this measurement mode resulted in measures that were more effective in capturing environmental differences meaningful to youth PA and sedentary behavior.

Direct observation of communities may be necessary to capture particular environmental features. Archival data sources (e.g., census data, commercially-available data on street networks) typically do not include street-level details and so may exclude key variables relevant to PA. For example, similar to Mantjes and colleagues (2012), who found an association between safe road crossings around schools (a street-level safety feature) and lower youth sedentary behavior, we observed associations between DO-safety and DO-recreation and lower sedentary behavior. A commonality of these two direct observation measures is the inclusion of walkability-related indicators such as the presence of sidewalks and bike lanes, which may provide a gauge of a safe, walkable environment that discourages sedentary behavior, at least in urban areas. CFA-recreation was not associated with sedentary behavior. Similar to DO-recreation, CFA-recreation included indicators for the presence of various types of recreational facilities, but did not include the walkability-related indicators that are better captured by direct observation.

Another difference between the two measurement modes was the larger number of indicators that were included in direct observation measures as compared to CFA measures. For example, CFA-utilitarian included just four indicators, whereas the three direct observation measures used to evaluate the utilitarian PA environment had between 15 and 33

indicators. With measurement error averaged out over a larger number of indicators, direct observation measures may more reliably capture environmental attributes. While the complexity of large composite measures may impede their use (Brownson et al., 2009), our findings tentatively suggest that reducing data to a few key indicators may not capture environmental differences that are meaningful to behavior. Direct observation may characterize environments more accurately by including a larger number of environmental features. Omission or inclusion of specific indicators could also impact the validity of environmental measures. For example, CFA-utilitarian, which only displayed a borderline association with youth's active transport to school in townships, might be strengthened by the inclusion of an indicator for destination accessibility, an important influence on walkability (Ewing and Cervero, 2010). However, including new indicators in CFA-derived measures would require additional analysis to determine whether indicators continue to measure a single latent construct.

One strength of this study was the comparison of two modes of objectively measuring the PA environments. By measuring environmental attributes directly we avoided same-source bias, which occurs when environmental measures and behavioral outcomes derive from self-reported data (Diez Roux, 2007). Additional strengths included the use of environmental measures specifically designed to evaluate a diverse study geography and examination of PA domain-specific environmental measures and behavioral outcomes. In addition to the issue of under powering described previously, a limitation of this study included the use of self-reported behavior. While combining parent and youth report of youth behavior provided a more reliable measure of behavior than simply relying on youth self-report, self-reported behavior remains subject to recall bias and social desirability bias (Chaumeton et al., 2011). If study participants over-reported PA and under-reported sedentary behavior, our associations would likely be biased toward the null. Objective measurement of youth PA (e.g. through accelerometry) can help overcome these biases, but has numerous disadvantages of its own (e.g., increased study burden and cost, reduced participation rates, long observation period to capture variations in PA over the days of the week and across seasons (Atkin et al., 2016)). We also lacked information on some psychometric properties of the behavioral outcomes and environmental measures—behavioral outcomes had demonstrated reliability but not validity, and the CASCADDE indices and CFA-derived measures had demonstrated construct validity but had not been assessed for reliability. Finally, the cross-sectional study design limited temporal inferences about the relationships between environmental measures and behavioral outcomes, a common problem for cross-sectional studies that is more intractable when considering the non-random selection of individuals into neighborhoods (Garfinkel-Castro et al., 2017; Glass and Bilal, 2016).

CONCLUSION

In this comparison of two strategies for objective, domain-specific measurement of PA environments, we found that neither direct observation nor CFA-derived measures were consistently associated with self-reported youth PA and sedentary behavior across diverse geographies. Direct observation measures performed better overall, indicating that this measurement mode resulted in measures that were more effective in capturing environmental differences meaningful to behavior. Direct observation of communities may be necessary to

capture important street-level details, and may characterize environments more accurately by including a larger number of environmental features. Overall, our findings highlight how evaluations can substantially differ based on the measurement mode researchers select. They also underline the importance of defining and differentiating community type in evaluating associations of the built environment with behavior, as well as the ongoing challenge of measuring meaningful differences in the built environment that influence youth behaviors across diverse geographies. Analyzing heterogeneous geographies is complicated by substantial differences in land use, built environment design, retailer and service mix, and transportation infrastructure, but is necessary for building a comprehensive understanding of the role of diverse environments in the obesity epidemic.

Acknowledgments

Funding: Research reported in this publication was supported by the Global Obesity Prevention Center (GOPC) at Johns Hopkins, and the Eunice Kennedy Shriver National Institute of Child Health and Human Development (NICHD) and the Office of the Director, National Institutes of Health (OD) under award number U54HD070725. The funders had no role in design and conduct of the study; collection, management, analysis, and interpretation of the data; or preparation, review, or approval of the manuscript. The content is solely the responsibility of the authors and does not necessarily represent the official views of the National Institutes of Health.

References

- American Academy of Pediatrics. The built environment: designing communities to promote physical activity in children. *Pediatrics*. 2009; 123:1591–1598. [PubMed: 19482771]
- Atkin AJ, Sharp SJ, Harrison F, Brage S, Van Sluijs EM. Seasonal Variation in Children's Physical Activity and Sedentary Time. *Med Sci Sports Exerc*. 2016; 48:449–456. [PubMed: 26429733]
- Bader MD, Ailshire JA, Morenoff JD, House JS. Measurement of the local food environment: a comparison of existing data sources. *Am J Epidemiol*. 2010; 171:609–617. [PubMed: 20123688]
- Bailey-Davis L, Poulsen MN, Hirsch AG, Pollak J, Glass TA, Schwartz BS. Food Rules in Relation to Youth Eating Behaviors, Body Mass Index, Waist Circumference, and Percent Body Fat. *J Adolesc Health*. 2017; 60:270–276. [PubMed: 27889403]
- Bringolf-Isler B, Kriemler S, Mader U, Dossegger A, Hofmann H, Puder JJ, Braun-Fahrlander C. Relationship between the objectively-assessed neighborhood area and activity behavior in Swiss youth. *Prev Med Rep*. 2014; 1:14–20. [PubMed: 26844034]
- Brownson RC, Hoehner CM, Day K, Forsyth A, Sallis JF. Measuring the built environment for physical activity: state of the science. *Am J Prev Med*. 2009; 36:S99–123. e112. [PubMed: 19285216]
- Carroll-Scott A, Gilstad-Hayden K, Rosenthal L, Peters SM, McCaslin C, Joyce R, Ickovics JR. Disentangling neighborhood contextual associations with child body mass index, diet, and physical activity: the role of built, socioeconomic, and social environments. *Soc Sci Med*. 2013; 95:106–114. [PubMed: 23642646]
- Carson V, Iannotti RJ, Pickett W, Janssen I. Urban and rural differences in sedentary behavior among American and Canadian youth. *Health Place*. 2011; 17:920–928. [PubMed: 21565545]
- Carver A, Timperio A, Crawford D. Playing it safe: the influence of neighbourhood safety on children's physical activity. A review. *Health Place*. 2008; 14:217–227. [PubMed: 17662638]
- Chastin SF, De Craemer M, Lien N, Bernaards C, Buck C, Oppert JM, Nazare JA, Lakerveld J, O'Donoghue G, Holdsworth M, Owen N, Brug J, Cardon G, Dedipac consortium, e.w.g., consensus, p. The SOS-framework (Systems of Sedentary behaviours): an international transdisciplinary consensus framework for the study of determinants, research priorities and policy on sedentary behaviour across the life course: a DEDIPAC-study. *Int J Behav Nutr Phys Act*. 2016; 13:83. [PubMed: 27421750]

- Chaumeton N, Duncan SC, Duncan TE, Strycker LA. A measurement model of youth physical activity using pedometer and self, parent, and peer reports. *International Journal of Behavioral Medicine*. 2011; 18:209–215. [PubMed: 20882445]
- de Vet E, de Ridder DT, de Wit JB. Environmental correlates of physical activity and dietary behaviours among young people: a systematic review of reviews. *Obes Rev*. 2011; 12:e130–142. [PubMed: 20630024]
- Diez Roux AV. Neighborhoods and health: where are we and where do we go from here? *Rev Epidemiol Sante Publique*. 2007; 55:13–21. [PubMed: 17320330]
- Ding D, Gebel K. Built environment, physical activity, and obesity: what have we learned from reviewing the literature? *Health Place*. 2012; 18:100–105. [PubMed: 21983062]
- Ding D, Sallis JF, Kerr J, Lee S, Rosenberg DE. Neighborhood environment and physical activity among youth: a review. *Am J Prev Med*. 2011; 41:442–455. [PubMed: 21961474]
- Ewing R, Cervero R. Travel and the built environment: A meta-analysis. *Journal of the American Planning Association*. 2010; 76:265–294.
- 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; 16:175–190. [PubMed: 19880341]
- Garfinkel-Castro A, Kim K, Hamidi S, Ewing R. Obesity and the built environment at different urban scales: examining the literature. *Nutr Rev*. 2017; 75:51–61. [PubMed: 28049749]
- Gebremariam MK, Altenburg TM, Lakerveld J, Andersen LF, Stronks K, Chinapaw MJ, Lien N. Associations between socioeconomic position and correlates of sedentary behaviour among youth: a systematic review. *Obes Rev*. 2015; 16:988–1000. [PubMed: 26317685]
- Giles-Corti B, Timperio A, Bull F, Pikora T. Understanding physical activity environmental correlates: increased specificity for ecological models. *Exerc Sport Sci Rev*. 2005; 33:175–181. [PubMed: 16239834]
- Glass TA, Bilal U. Are neighborhoods causal? Complications arising from the ‘stickiness’ of ZNA. *Soc Sci Med*. 2016; 166:244–253. [PubMed: 26830654]
- Hansen AY, Umstadtd Meyer MR, Lenardson JD, Hartley D. Built Environments and Active Living in Rural and Remote Areas: a Review of the Literature. *Curr Obes Rep*. 2015; 4:484–493. [PubMed: 26364307]
- Howe, LD., Firestone, R., Tilling, K., Lawlor, DA. Trajectories and Transitions in Childhood and Adolescent Obesity. In: Burton-Jeangros, C.Cullati, S.Sacker, A., Blane, D., editors. *A Life Course Perspective on Health Trajectories and Transitions*, Cham (CH). 2015.
- Joe L, Carlson JA, Sallis JF. Active Where? Individual item reliability parent/statistics adolescent survey.
- Kenney MK, Wang J, Iannotti R. Residency and racial/ethnic differences in weight status and lifestyle behaviors among US youth. *J Rural Health*. 2014; 30:89–100. [PubMed: 24383488]
- Knapp EA, Nau C, Brandau S, DeWalle J, Hirsch AG, Bailey-Davis L, Schwartz BS, Glass TA. Community Audit of Social, Civil, and Activity Domains in Diverse Environments (CASCADDE). *Am J Prev Med*. 2017; 52:530–540. [PubMed: 28209283]
- Liu JH, Jones SJ, Sun H, Probst JC, Merchant AT, Cavicchia P. Diet, physical activity, and sedentary behaviors as risk factors for childhood obesity: an urban and rural comparison. *Child Obes*. 2012; 8:440–448. [PubMed: 23061499]
- Mantjes JA, Jones AP, Corder K, Jones NR, Harrison F, Griffin SJ, van Sluijs EM. School related factors and 1yr change in physical activity amongst 9-11 year old English schoolchildren. *Int J Behav Nutr Phys Act*. 2012; 9:153. [PubMed: 23276280]
- Moore JB, Beets MW, Morris SF, Kolbe MB. Comparison of objectively measured physical activity levels of rural, suburban, and urban youth. *Am J Prev Med*. 2014; 46:289–292. [PubMed: 24512868]
- Moore JB, Brinkley J, Crawford TW, Evenson KR, Brownson RC. Association of the built environment with physical activity and adiposity in rural and urban youth. *Prev Med*. 2013; 56:145–148. [PubMed: 23219761]
- Oliver M, Badland H, Mavoa S, Witten K, Kearns R, Ellaway A, Hinckson E, Mackay L, Schluter PJ. Environmental and socio-demographic associates of children's active transport to school: a cross-

sectional investigation from the URBAN Study. *Int J Behav Nutr Phys Act.* 2014; 11:70. [PubMed: 24888516]

Popkin BM, Duffey K, Gordon-Larsen P. Environmental influences on food choice, physical activity and energy balance. *Physiol Behav.* 2005; 86:603–613. [PubMed: 16246381]

Sallis JF, Floyd MF, Rodriguez DA, Saelens BE. Role of built environments in physical activity, obesity, and cardiovascular disease. *Circulation.* 2012; 125:729–737. [PubMed: 22311885]

Sallis JF, Glanz K. Physical activity and food environments: solutions to the obesity epidemic. *Milbank Q.* 2009; 87:123–154. [PubMed: 19298418]

Schaefer-McDaniel N, Dunn JR, Minian N, Katz D. Rethinking measurement of neighborhood in the context of health research. *Social Science & Medicine.* 2010; 71:651–656. [PubMed: 20579796]

Schwartz BS, Bailey-Davis L, Bandeen-Roche K, Pollak J, Hirsch AG, Nau C, Liu AY, Glass TA. Attention deficit disorder, stimulant use, and childhood body mass index trajectory. *Pediatrics.* 2014; 133:668–676. [PubMed: 24639278]

Schwartz BS, Stewart WF, Godby S, Pollak J, Dewalle J, Larson S, Mercer DG, Glass TA. Body mass index and the built and social environments in children and adolescents using electronic health records. *Am J Prev Med.* 2011; 41:e17–e28. [PubMed: 21961475]

Stierlin AS, De Lepeleere S, Cardon G, Dargent-Molina P, Hoffmann B, Murphy MH, Kennedy A, O'Donoghue G, Chastin SF, De Craemer M, consortium D. A systematic review of determinants of sedentary behaviour in youth: a DEDIPAC-study. *Int J Behav Nutr Phys Act.* 2015; 12:133. [PubMed: 26453175]

Su JG, Jerrett M, McConnell R, Berhane K, Dunton G, Shankardass K, Reynolds K, Chang R, Wolch J. Factors influencing whether children walk to school. *Health Place.* 2013; 22:153–161. [PubMed: 23707968]

Swinburn B, Egger G, Raza F. Dissecting obesogenic environments: the development and application of a framework for identifying and prioritizing environmental interventions for obesity. *Prev Med.* 1999; 29:563–570. [PubMed: 10600438]

Swinburn BA, Sacks G, Hall KD, McPherson K, Finegood DT, Moodie ML, Gortmaker SL. The global obesity pandemic: shaped by global drivers and local environments. *Lancet.* 2011; 378:804–814. [PubMed: 21872749]

Timperio A, Reid J, Veitch J. Playability: Built and Social Environment Features That Promote Physical Activity Within Children. *Curr Obes Rep.* 2015; 4:460–476. [PubMed: 26399255]

HIGHLIGHTS

- Community features influence youth behavior, requiring evaluation of diverse places
- We compared two strategies for measuring built environments across diverse places
- Both measurement strategies captured differences in environmental features
- Neither was consistently associated with physical activity or sedentary behavior
- The study of diverse geographies poses methodological challenges

Figure 1. Scatterplot of the two environmental measures of the fitness and recreation environment (CFA-recreation and DO-recreation) by community type with lowess line

Figure 2. Scatterplots depicting relations between the four environmental measures of the utilitarian physical activity environment (CFA-utilitarian, DO-barriers, DO-safety, DO-commercialization) by community type with loess lines

Figure 3.

Adjusted¹ associations (ORs, 95% CIs) between measures of the utilitarian PA environment and active transport to school

Abbreviations: DO-barriers = barriers to physical activity index; DO-safety = environmental features that promote safety index; DO-commercialization = commercial and civic intensity index; CFA-utilitarian = utilitarian physical activity favorability factor

¹All models were stratified by community type and adjusted for youth age, youth sex, youth race/ethnicity (white, black, other/missing), and youth Medical Assistance as described in Methods.

Figure 4.

Adjusted¹ associations (betas, 95% CIs) between all PA environment measures and sedentary behavior

Abbreviations: DO-recreation = physical activity promoting features index; CFA-recreation = fitness and recreational assets factor; DO-barriers = barriers to physical activity index; DO-safety = environmental features that promote safety index; DO-commercialization = commercial and civic intensity index; CFA-utilitarian = utilitarian physical activity favorability factor

¹All models were stratified by community type and adjusted for youth age, youth sex, youth race/ethnicity (white, black, other/missing), and youth Medical Assistance as described in Methods

Table 1

Summary of PA environmental measures and the behavioral outcomes assessed for each PA environment domain

Method of Measurement	Measures by PA Environment Domain	
	Utilitarian Physical Activity Environment	Fitness and Recreational Environment
Direction observation (CASCADDE indices)	Barriers to physical activity (DO-barriers) 15 items <i>such as lack of public lighting, heavy traffic, walking barriers (e.g., highways, undeveloped land)</i> Environmental features that promote safety (DO-safety) 27 items <i>such as presence of traffic control devices, sidewalks, and bike lanes, condition of streets</i> Commercial and civic intensity (DO-commercialization) 33 items <i>such as presence of commercial, civic, and industrial establishments, public facilities, parking, bus stops</i>	Physical activity promoting features (DO-recreation) 27 items <i>such as types of recreational facilities present (e.g., playgrounds, recreational centers, playing fields), presence of sidewalks/bike lanes, condition of sidewalks, walkability</i>
Archival data (CFA factors)	Utilitarian physical activity favorability (CFA-utilitarian) 4 indicators: <i>household density, vehicle miles traveled per capita, average block length, street connectivity</i>	Fitness and recreational assets (CFA-recreation) 6 indicators: <i>density of indoor fitness clubs, outdoor recreational clubs and organizations, and indoor recreational clubs and organizations; diversity of fitness and recreational places and types of food establishments; count of outdoor public parks and recreational spaces</i>
Behavioral Outcomes	Active transport to school Sedentary behavior	Organized out-of-school physical activity Sedentary behavior

Table 2

Characteristics of youth, parents, and communities by community type

Characteristic	Township <i>n</i> = 198 youths	Borough <i>n</i> = 130 youths	City <i>n</i> = 97 youths
Youth demographics			
Female sex, <i>n</i> (%)	104 (53)	70 (54)	46 (47)
Age, years, median (IQR)	13 (11, 14)	13 (12, 15)	13 (12, 14)
Race/ethnicity, <i>n</i> (%)			
White	186 (94)	122 (94)	83 (86)
Black	9 (5)	5 (4)	9 (9)
Hispanic	0 (0)	2 (2)	1 (1)
Other	3 (2)	1 (1)	4 (4)
Received Medical Assistance, <i>n</i> (%)	51 (26)	50 (39)	48 (50)
Parent demographics			
Female sex, <i>n</i> (%)	166 (84)	104 (80)	83 (86)
Age, years, median (IQR)	43 (37, 47)	42 (38, 47)	40 (34, 47)
Youth behaviors (study outcomes)			
Active transport to school, <i>n</i> (%) ¹	35 (18)	55 (42)	50 (52)
Average weekly hours per sedentary behavior, median (IQR)	6.5 (4.5, 8.8)	7.5 (5.4, 11.7)	7.7 (5.5, 10.3)
Organized out-of-school physical activity, <i>n</i> (%)			
0 hours	63 (32)	62 (48)	46 (47)
1 to 2.5 hours	44 (22)	20 (15)	19 (20)
>2.5 hours to <5.5 hours	43 (22)	22 (17)	21 (22)
5.5 hours	48 (24)	26 (20)	11 (11)
Community characteristics			
Communities, <i>n</i>	11 / 13	9 / 11	8 / 6
Population density ² , 2010, population/sq. mile, median (IQR)	391 (153, 433)	2895 (1141, 6378)	7295 (4997, 9389)
Community socioeconomic deprivation, 2000 (SD units), median (IQR)	−0.44 (−0.79, −0.16)	(−0.25 0.07, 1.10)	1.14 (0.93, 1.59)
Community mean BMI for youth aged 10-15 ³	21.8	22.3 22.8	
% 85th percentile	35	40	44
% 95th percentile	18	23	26
PA environment measures			
Fitness and recreational environment			
DO-recreation, median (IQR)	3.1 (2.3, 3.4)	5.4 (4.9, 6.4)	4.4 (4.4, 6.2)
CFA-recreation, median (IQR)	1.8 (0.28, 5.9)	5.3 (3.1, 7.9)	4.3 (3.3, 5.4)
Utilitarian physical activity environment			
DO-barriers, median (IQR)	2.3 (2.1, 3.1)	0.9 (0.9, 1.4)	0.9 (0.9, 1.4)
DO-safety, median (IQR)	5.7 (4.8, 6.3)	9.2 (7.3, 10.2)	9.5 (6.7, 9.5)
DO-commercialization, median (IQR)	1.5 (0.7, 1.6)	3.4 (2.6, 4.2)	3.7 (3.7, 4.2)

Characteristic	Township <i>n</i> = 198 youths	Borough <i>n</i> = 130 youths	City <i>n</i> = 97 youths
CFA-utilitarian, median (IQR)	−0.5 (−1.2, 0.1)	2.4 (1.0, 2.8)	4.0 (3.1, 4.3)

Abbreviations: IQR, interquartile range

¹ Active transport to school outcome missing data for 11 youths

² Population density based on 2010 U.S. Census

³ Community mean BMI based on Geisinger Clinic data for 2008–2012

Table 3

Correlations (Spearman's rho) between environmental measures of the utilitarian PA environment

	DO-barriers	DO-safety	DO-commercialization
CFA-utilitarian	Overall: -0.83 Townships: -0.43 Boroughs: -0.43 Cities: -0.51	Overall: 0.66 Townships: 0.55 Boroughs: 0.30 Cities: -0.25	Overall: 0.74 Townships: 0.60 Boroughs: -0.23 Cities: -0.03
DO-commercialization	Overall: -0.69 Townships: -0.04 Boroughs: 0.10 Cities: -0.12	Overall: 0.75 Townships: 0.49 Boroughs: 0.20 Cities: 0.09	
DO-safety	Overall: -0.69 Townships: -0.48 Boroughs: -0.24 Cities: 0.21		

Abbreviations: DO-barriers = barriers to physical activity index; DO-safety = environmental features that promote safety index; DO-commercialization = commercial and civic intensity index; CFA-utilitarian = utilitarian physical activity favorability factor

Table 4Summary of associations^I of PA environmental measures with youth behavioral outcomes by community type

Environmental Measures	Youth Behavioral Outcomes	
Utilitarian PA environment measure	Active transport to school	Sedentary behavior
DO-barriers		
Townships	None	None
Boroughs/cities	(-)	None
DO-safety		
Townships	None	None
Boroughs/cities	None	(-)
DO-commercialization		
Townships	(Borderline +)	(+)
Boroughs/cities	None	None
CFA-utilitarian		
Townships	(Borderline +)	None
Boroughs/cities	None	None
Fitness and recreation environment measure	Hours of organized out-of-school PA	Sedentary behavior
DO-recreation		
Townships	None	None
Boroughs/cities	None	(Borderline -)
CFA-recreation		
Townships	None	None
Boroughs/cities	5.5 hours: (+)	None

Abbreviations: DO-recreation = physical activity promoting features index; CFA-recreation = fitness and recreational assets factor; DO-barriers = barriers to physical activity index; DO-safety = environmental safety index; DO-commercialization = commercial and civic intensity index; CFA-utilitarian = utilitarian physical activity favorability factor

^I All models were stratified by community type and adjusted for youth age, youth sex, youth race/ethnicity (white, black, other/missing), and youth Medical Assistance as described in Methods.

(+) and (-) indicate whether associations were positive or negative.