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Built environment associations with adiposity parameters among overweight and obese Hispanic youth

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ABSTRACT

Objective. The purpose of this cross-sectional study was to establish neighborhood built environment correlates of adiposity as measured by dual X-ray absorptiometry. The utility and methodological gains of using this measure for built environment research were further investigated by comparing model fit across parallel models on body mass index z-scores and waist circumference.

Methods. Pre-existing data collected from 2001 to 2011 on 576 overweight and obese Hispanic youth were compiled with built environment data, and 2000 census data for analyses conducted in 2012. Walking-distance buffers were built around participants' residential locations. Variables for park space, food access, walkability, and neighborhood socio-cultural aspects were entered into a multivariate regression model predicting percent body fat. Parallel models were built for body mass index z-score, and waist circumference.

Results. Significant associations were found between percent body fat and supermarket access for boys, and percent body fat and increased park space and decreased neighborhood linguistic isolation for girls. Neighborhood socio-cultural characteristics accounted for more variance in obesity compared to body mass index z-score or waist circumference.

Conclusion. Park access, food environment, and neighborhood socio-cultural characteristics are independent contributors to body fat in children, and the contribution of these risks differs by gender. There are incremental gains to using a more accurate measure of body fat in built environment obesity studies.

Introduction

Prevalence of childhood obesity is increasing, particularly among Hispanic children and adolescents (Ogden et al., 2012). In response, researchers and policy makers have intervened on aspects of the neighborhood built environment to improve diet and increase physical activity (Sallis and Glanz, 2009; Rahman et al., 2011). Associations with BMI have been detected for a wide range of neighborhood-level exposures including food access (Morland et al., 2002; Spence et al., 2009; Galvez et al., 2009), walkability (Cohen et al., 2007; Gordon-Larsen et al., 2006), and neighborhood socio-economic status (Gordon-Larsen et al., 2006; Everson et al., 2002; Gordon-Larsen et al., 2003), but the evidence for these associations remains inconsistent (Caspi et al., 2012; Ding and Gebel, 2012). Despite the high prevalence of obesity in Hispanic populations and evidence of racial disparities in the association between built environmental factors and obesity outcomes (Duncan et al., 2012; Duncan et al., 2014a), there have been relatively few studies that investigate built environment influences among Hispanic youth.

Efforts to establish a stronger evidence base have focused on improving the validity and reliability of objective and perceived measures of the built environment (Giskes et al., 2011), and more accurately defining the

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neighborhood (Tatalovich et al., 2006). However, relatively little attention is given to the choice of outcome measurement (Boone-Heinonen et al., 2010; Brownson et al., 2009; Bader et al., 2010). Differences in accuracy and repeatability of direct and indirect measures of adiposity may obscure associations produced by the diffuse effects of environmental influences.

Dual X-ray absorptiometry (DXA) can accurately and precisely measure lean, fat and mineral body composition. It is commonly used in obesity research to determine body fat percent and has strong correlation with magnetic resonance imaging (MRI) and computed tomography (CT) among children and adults (Bridge et al., 2011; Kendler et al., 2013; Gradmark et al., 2010). DXA is often used as the "gold-standard" measurement of body fat in validation studies of anthropometric measurements of obesity in both adult and pediatric populations (Wohlfahrt-Veje et al., 2014; Liu et al., 2015; Freedman and Sherry, 2009; Direk et al., 2013). This study presents several novel contributions. First, this study is unique in its application of DXA to identify built environmental correlates to obesity risk among a sample of overweight and obese Hispanic youth. Second, aspects of food environment and physical activity environment will be investigated simultaneously. While both food environment and physical activity environment influences on obesity risk have been substantially investigated (Caspi et al., 2012; Ding and Gebel, 2012), both facets of the built environment are rarely addressed in a single study.

Third, the results from this analysis are compared using parallel regression models with two commonly used adiposity parameters, BMI z-score (BMIZ) and waist circumference (WC). This comparison of multiple measures of adiposity illuminates how choice of outcome measurement can affect relationships to the built environment.

The primary aims of this study are two-fold: (1) to analyze the relationship between aspects of the built environment and percent body fat (%BF) as measured by DXA, and (2) to compare results with those obtained using two common indirect measures of adiposity, BMIZ and WC, in a sample of overweight and obese youth. To achieve these aims, this study utilized extant data from the University of Southern California Childhood Obesity Research Center (USC CORC) studies of overweight and obese Hispanic Youth. These data were combined into a database of built environment variables covering Los Angeles County. There were three hypotheses for this study: (1) access to supermarkets, parks, and dense street networks would be negatively associated with %BF, (2) increased density of restaurants would be positively associated with %BF, and (3) the built environment would explain more variance in %BF than in BMIZ and/or in WC.

Methods

Participant recruitment and procedures

Baseline data from six studies at the USC CORC were compiled for this analysis (Cruz et al., 2004; Davis et al., 2009; Davis et al., 2011; Spruijt-Metz et al., 2012; Toledo-Corral et al., 2012; Weigensberg et al., 2009). Criteria for inclusion in the current analyses were: (1) Hispanic ethnicity, (2) having an age- and sex-specific BMI $\geq$85th percentile, (3) no previous major illness, including type 1 or 2 diabetes, no medications, or conditions known to influence body composition, insulin action, or insulin secretion, (4) not meeting diagnostic criteria for diabetes at the time of screening, and (5) not having engaged in any structured weight loss intervention 6 months before the study. This study and the USC CORC studies that contributed data to it were approved by the Health Sciences Institutional Review Board at USC.

All studies used similar recruitment sites, including Los Angeles area health clinics and word-of-mouth, located in urban areas of Los Angeles with a dense population of Hispanic residents. Dates of baseline data collection ranged from 2001 to 2011. All studies followed similar data collection protocols, which permitted data harmonization across studies for a combined analysis.

Participant data were collected during a medical history exam by a trained medical professional at the USC Clinical Trials Unit (CTU), where age and Tanner pubertal stage were determined, weight was measured to the nearest 0.1 kg, height was measured in duplicate to the nearest 0.1 cm and WC was measured to the nearest 0.1 cm. BMIZ for age and sex was determined using CDC 2000 standards. Percent BF was measured using DXA on a Hologic QDR 4500 W (Waltham, Massachusetts).

Walking-distance buffers

Participants' addresses were geocoded using ArcGIS (Version 10, ESRI, Redlands, CA) automated procedures within 50 m of the nearest street segment. These point locations were used to create geographic buffers representing the walkable environment which could theoretically impact youths' residential neighborhood-based food and physical activity behaviors (Rundle et al., 2009).

ArcGIS Network Analyst was used to generate walking-distance buffers by traversing all possible routes for a given distance on a street network away from a location (Freedman and Sherry, 2009; Direk et al., 2013). Distances of half-mile, one-mile, and two-miles were chosen to reflect a range of reasonable walking distances. The resulting buffers more accurately capture neighborhood exposure based on actual travel distances than circular buffers (Oliver et al., 2007). Fig. 1 depicts an example area with half- and one-mile walking-distance buffers, with an inset detailing an example half-mile walking-distance buffer, with an example route and end-point.

Neighborhood built environment variables

Food environment

Supermarket and restaurant locations in Los Angeles County were extracted from a 2010 InfoUSA database. Extended North American Industry Classification System code 44511003 was used to identify supermarkets. Because large supermarkets are more likely to be a source of fresh fruits and vegetables (Cruz et al., 2004; Davis et al., 2009), only supermarkets larger than 10,000 sq. ft. were included. All restaurants were extracted using codes 72211001–72211020, 72221101–72221105, 72221201–72221202, and 72221301–72221320. Counts of restaurants and supermarkets were calculated within each half-, one-, and two-mile buffer.

Physical activity environment

Neighborhood walkability was operationalized as street junctions per square mile. A 2010 ESRI street map was used to calculate the number of street connections involving at least three street segments per square mile. Park access was operationalized as aggregate park space in acres for each buffer. Park data from 2007 were provided by the GreenVision plan for 21st Century Southern California (Sister et al., 2009).

Neighborhood socio-cultural characteristics

To reflect the broader social and cultural context in which these built environmental exposures are situated, aspects of the neighborhood socio-cultural environment were operationalized using Census tract boundaries, which can delineate a relatively homogenous population with respect to social and economic characteristics (Krieger et al., 1997). Census 2000 data on median household income among Hispanic households, and Spanish-speaking households who reported being linguistically isolated were used to examine the impact of neighborhood-level social and economic characteristics. Linguistic isolation was defined by the Census as households where the respondent reported that no adults speak English "very well". Neighborhood linguistic isolation, as a measure of neighborhood-level acculturation, was calculated as the proportion of Spanish speaking households reporting to be linguistically isolated from the total number of households in a Census tract.

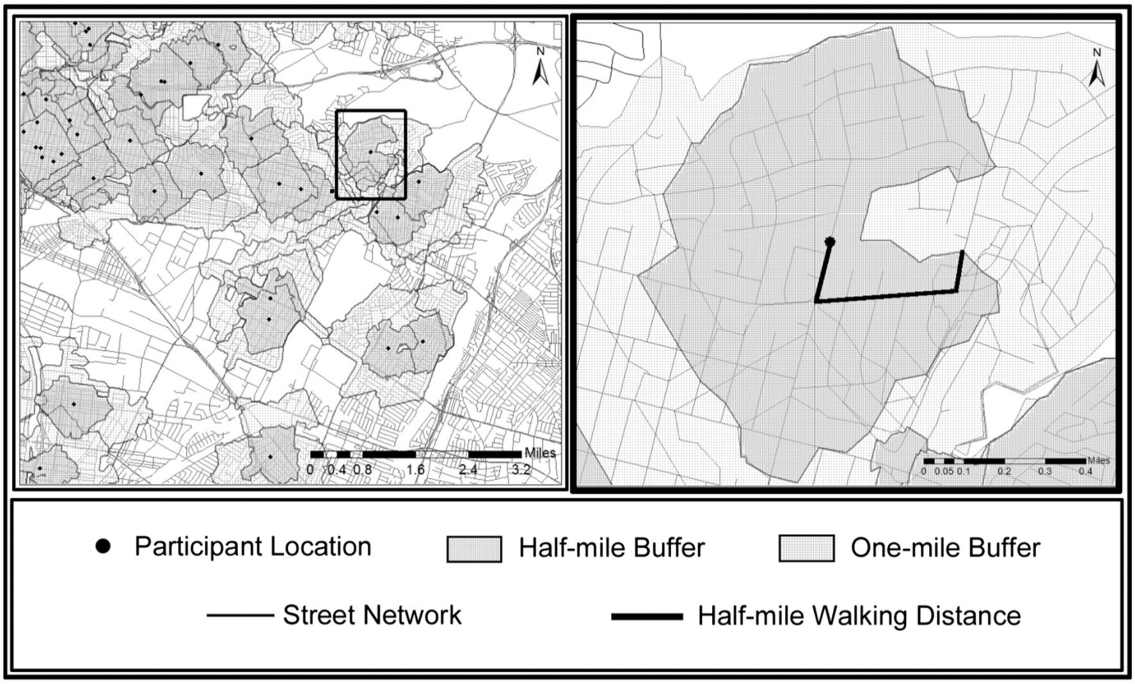

Fig. 1. Example half- and one-mile walking-distance buffers (left) and zoomed in half-mile walking-distance buffer for a study participant (right).

Geocoding

Data on 592 overweight and obese participants with addresses were assembled. Automatic procedures in ArcGIS were used to geocode participant locations using the ESRI StreetMap base map (ESRI, Redlands, CA). Two percent of the addresses (n = 12) did not automatically match to a location. Interactive matching was performed on these addresses to check for correctable errors in address format or spelling. All addresses except one were successfully matched after correcting these errors. Participants were geocoded into 285 census tracts in Los Angeles County. Fifteen participants geocoded to locations outside of LA County were excluded from the analysis, creating an analytic sample of 576 participants.

Statistical analysis

Univariate analysis

All statistical analyses were carried out in 2012 using SAS version 9.2 (SAS institute, Cary, NC), to establish built environmental correlates to adiposity. Univariate statistics and distributions were generated for all predictor, outcome and control variables. Based on distributions produced during univariate analyses, park access and food access variables were dichotomized to prevent violation of the normality assumption during regression analysis. Parks access and restaurants were dichotomized at the median of their respective distributions to create “high” and “low” categories. Supermarkets were dichotomized to having at least one supermarket within a two-mile buffer.

Bivariate analysis

Pearson correlation coefficients were used to assess pair-wise associations between %BF and each built environment variable. This analysis was carried at all three buffer sizes. Significant correlations between %BF and the neighborhood environment were most consistently found using half-mile buffers, with the exception of supermarkets, which was significant only at the two-mile buffer size. Built environment variables with significant correlations with %BF were retained for regression analysis.

Regression analysis

Preliminary multi-level linear regression models were built with the individual level nested within Census tracts. The random effect representing Census tract variance was found to be non-significant. Therefore, linear regression models were used to model %BF. All models were adjusted for age, Tanner stage, and neighborhood socio-cultural characteristics. Semi-variograms were calculated from the residuals of the final linear regression models to check for residual-spatial autocorrelation (Waller and Gotway, 2004).

The final linear regression model predicting %BF was used to model BMIZ and WC to compare the consistency of built environment associations across obesity measures.

Results

Sample characteristics

Fig. 2 depicts the geographic distribution of study participants across LA County by percent Hispanic population. Study participants were most concentrated in the East LA and in Northeast LA County. Table 1 contains univariate descriptors for study participants, neighborhood built environment, and socio-cultural characteristics. Significant differences in the relationship between neighborhood environment and body fat were found by sex. Therefore, all data presented are stratified by sex. Ages ranged from eight to eighteen. Mean %BF was 36% for males and 40% for females. For both sexes, participants lived in neighborhoods with an average of one supermarket within two miles. BMIZ contained the least variability of the three adiposity measures, having the smallest standard deviation relative to the mean value (males: mean = 2.13, sd = 0.45; females: mean = 2.02, sd = 0.41) while WC contained the most variability (males: mean = 94.83, sd = 16.56; females: mean = 91.75, sd = 15.58).

A total of 272 males were located across 122 Census tracts, and a total of 304 girls were located across 161 Census tracts. Participants represented Census tracts that were densely populated by lower income Hispanics. Mean Hispanic household median income from the 2000 Census was approximately $32,000 among Census tracts containing

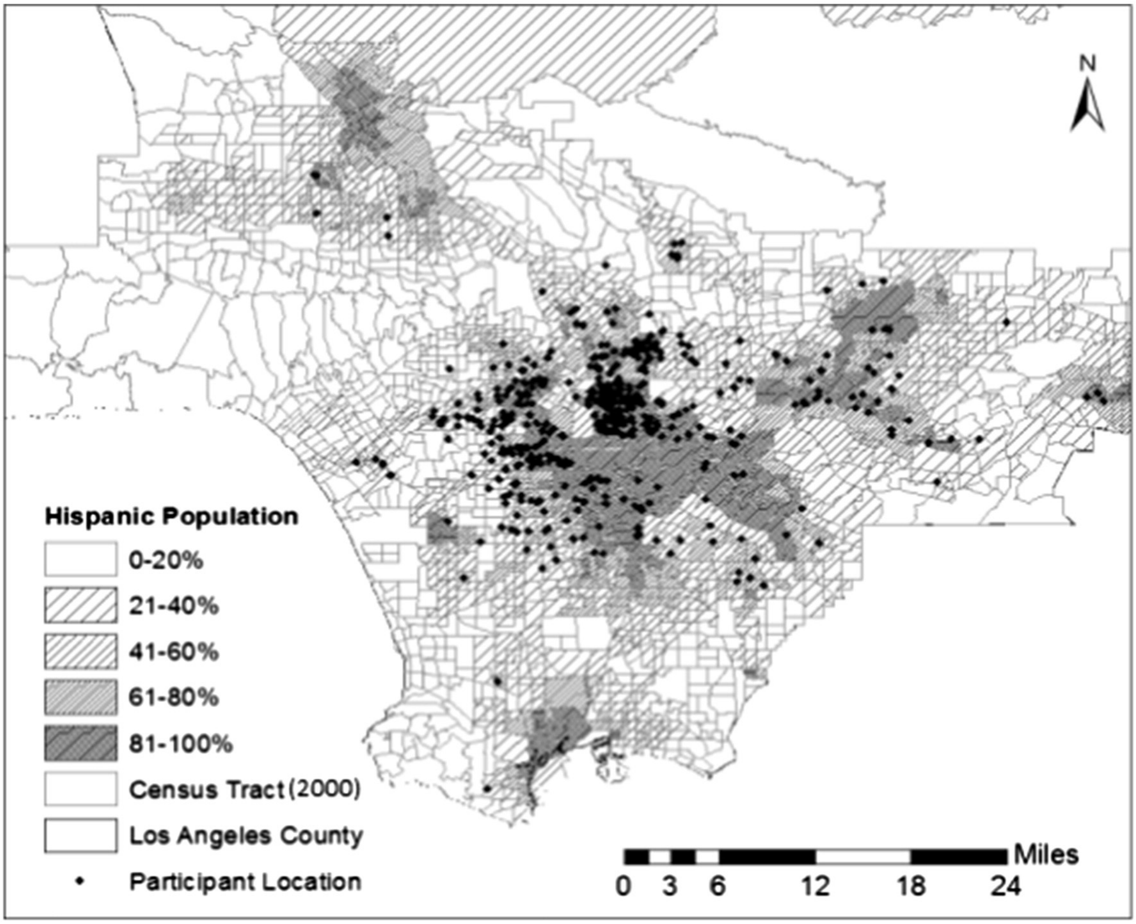

Fig. 2. Distribution of participant locations (N = 576) across Los Angeles County.

boys and $30,000 among Census tracts containing girls. The rate of neighborhood linguistic isolation in Census tracts was approximately 33% for Census tracts containing boys and 35% for Census tracts containing girls.

Neighborhood environment and %BF

Table 2 displays the Pearson correlation coefficients between adiposity measures and neighborhood environment variables. BMIZ was strongly correlated with WC ($r = 0.706$, $p < 0.001$), but less so with %BF ($r = 0.597$, $p < 0.001$). WC was more weakly correlated to %BF than BMIZ ($r = 0.432$, $p < 0.001$). The built environment variables were also collinear. While these correlations were not strong, they were present throughout the data, particularly with neighborhood socio-cultural characteristics.

Regression parameters for the final model predicting %BF are presented in Table 3. Model fit statistics (R^2) indicate 28% of the variance in %BF was accounted for in boys compared to 13% among girls. Boys who have a supermarket within two miles have 2.73% less %BF compared to similar boys without a supermarket. Among girls, living in neighborhoods with more than three acres of park space is associated with having an average of 1.4% less %BF than similar girls living in similar neighborhoods with less than three acres of park space while. Neighborhood linguistic isolation

Table 1
Individual, buffer, and neighborhood characteristics of the study sample.

	Male					Female				
	N	Mean	Std. Dev.	Min	Max	N	Mean	Std. Dev.	Min	Max
Individual characteristics										
Age, years	272	12.6	2.6	8	18	304	13.2	2.8	8	18
Tanner pubertal stage	263	2.7	1.7	1	5	297	3.7	1.5	1	5
Percent body fat, %	231	36.1	7.2	11.2	52.3	250	40.5	4.95	25.9	54.2
Waist circumference, cm	249	94.8	16.5	44.1	147	240	91.7	15.6	58.5	143
BMI z-score	254	2.1	0.5	1.1	3.2	292	2	0.4	1.1	2.9
Buffer characteristics										
Supermarkets, # (two-mile buffer)	264	1.1	1.3	0	7	300	1	1.1	0	5
Restaurants, # (half-mile buffer)	264	10.9	11.4	0	71	300	11.2	12.6	0	102
Junctions/sq. mi. (half-mile buffer)	264	271	131	73.2	796	300	274	130	64.5	762
Park acres, # (half-mile buffer)	264	4.2	6.1	0	46.9	300	5.1	7.3	0	47.3
Neighborhood characteristics (by Census tract)										
Median Hispanic household income, $1000's	122	32.7	10.9	14.6	71.0	161	30.1	12.7	7.3	135
Linguistic isolation, %	122	33.5	14.1	2.4	67.6	161	35.3	13.73	0	75.9

Table 2
Pearson correlation coefficients between individual and neighborhood environment variables and outcome measures.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
(1) Age, y	1											
(2) Sex	**0.118***	1										
(3) Tanner pubertal stage	**0.842***	**0.326***	1									
(4) Body fat, %	0.011	**0.335***	−0.024	1								
(5) BMI z-score	**0.072**	**−0.131***	**0.074**	**0.597***	1							
(6) Waist circ., cm	**0.530***	**−0.095***	**0.428***	**0.432***	**0.706***	1						
(7) Supermarkets, #	0.008	−0.052	0.011	−0.075	−0.036	−0.025	1					
(8) Restaurants, #	0.008	0.008	0.006	−0.015	−0.041	−0.034	**0.425***	1				
(9) Junctions/sq. mi.	0.057	0.012	0.064	**−0.133***	**−0.094***	−0.049	**−0.285***	−0.015	1			
(10) Park acres, #	0.008	0.065	0.015	0.063	0.024	0.044	0.039	**0.110***	−0.016	1		
(11) Median Hispanic household income, $	**−0.106**	**−0.074***	**−0.110***	0.015	0.039	−0.008	**−0.128***	**−0.346***	**−0.223***	−0.061	1	
(12) Linguistically isolation, %	0.056	**0.090***	0.043	0.015	−0.045	0.002	**0.335***	**0.484***	**0.127***	**0.105***	**−0.720***	1

Note: Pearson correlation coefficients, $p < 0.10$ are in bold.
* $p < 0.05$.

was associated with slightly increased %BF in girls where a 10 percentage point difference in neighborhood linguistic isolation is associated with a 0.78 percentage point difference in %BF.

Adiposity parameters

Table 4 compares the percent of variance explained by age and Tanner stage, the neighborhood SES, and the neighborhood built environment. While overall model fit varied by sex, these differences were due mainly to age and Tanner pubertal stage. Neighborhood socio-cultural characteristics explained 1% of the variation in %BF among both boys and girls, while the neighborhood built environment explained an additional 7% among boys and an additional 6% among girls.

The final model had the poorest model fit for BMIZ. Only 8% of the variance among boys, and 9% among girls, is explained. The built environment independently explains 6% of the variation among boys, with the remaining 2% explained by individual and socio-cultural characteristics. For girls, 3% of the variation is explained by the built environment, and an additional 2% is explained by individual and socio-cultural characteristics.

The final model explained 37% of the variation in WC among girls, but this was largely due to the individual characteristics of age and Tanner pubertal stage. Despite having the best overall model fit, neighborhood built environment explained only 3% of the variance in girls' WC. Among boys, the pattern is similar, with 5% of the variation explained by differences in the built environment and 27% of the variation explained by age and Tanner stage.

Table 3
Regression coefficients for linear regression models predicting percent body fat, stratified by sex.

Variable	Male		Female	
	β coef.	p	β coef.	p
Intercept	**37.872**	**<0.001**	**42.632**	**<0.001**
Age, centered at 13 years	**0.675**	**0.025**	**0.488**	**0.034**
Tanner pubertal stage, centered at stage III	**−2.779**	**<0.001**	−0.017	0.966
At least 1 large supermarket (two-mile buffer)	**−2.726**	**0.004**	−1.141	0.096
More than 8 restaurants (half-mile buffer)	−1.139	0.220	−1.243	0.061
Junctions/sq. mi. (half-mile buffer)	**−0.012**	**<0.001**	−0.004	0.070
At least 3 acres of park space (half-mile buffer)	0.137	0.883	**−1.431**	**0.036**
Hispanic household income (in $1000's), centered at $30,000	−0.058	0.404	0.046	0.223
Linguistic isolation, centered at 35%	−0.031	0.566	**0.078**	**0.025**
R^2	0.28		0.13	
Number of observations used	217		240	

Note: Coefficients and p-values for estimates significantly different from 0 at the $p < 0.05$ are in bold.

Discussion

The use of DXA as a measure of obesity in built environment research yielded important substantive and methodological insights. Supermarket access and higher street connectivity are related to lower %BF among boys, and increased park access is related to lower %BF among girls. These findings are consistent with current research that suggests that food access, physical activity environment, and neighborhood socio-cultural aspects are all independent contributors to obesity risk (Sallis and Glanz, 2009; Caspi et al., 2012; Giskes et al., 2011). They are also consistent with studies that have shown that the contribution of built environmental factors to obesity risk differs by gender (Wolch et al., 2011; Wang et al., 2007). We speculate that these differences might arise from different behavior expectations between boys and girls. Other examples of gender-specific associations in the built environment have been found. For example, parents' perception of neighborhood is associated with children's active transit to school with different associations occurring for boys and girls. Perception of the neighborhood environment was also different between girls and boys (Timperio et al., 2004). Hispanic neighborhoods are more likely to have fewer recreation facilities and less funding to build and maintain those facilities compared to non-Hispanic White (NHW) neighborhoods (Moore et al., 2008; Wolch et al., 2005). Hispanic neighborhoods are also more likely than NHW neighborhoods to lack access to a large supermarket (Powell et al., 2007). Results from this study indicate that improvements to neighborhood access to parks and large supermarkets could have a meaningful impact on obesity rates in this vulnerable population. Importantly, they also indicate that this increased access could benefit children who are already overweight or obese. With the current prevalence of childhood overweight and obesity over 30% (Ogden et al., 2014), this population represents a substantial portion of the youth population that warrants specific attention, but there are very few studies that focus on neighborhood environmental factors affecting children who are already overweight or obese (Fiechtner et al., 2013). These findings represent a valuable addition to the built environment research among children who are already overweight or obese.

Further novel findings from this study are that the built environment explained more variance in DXA compared to BMIZ and WC. Measures of adiposity differ in their degree of reliability, comparability across population groups, cost, feasibility, and value as predictors of morbidity and mortality. Although DXA is an accurate way of directly measuring body fat, it requires costly equipment and training, is time consuming, and exposes study participants a small amount of radiation. Thus, studies often employ indirect measures, which are logistically easier to obtain and lower in cost, such as BMI and WC (Stevens et al., 2008).

Although reasonably easy to obtain, BMI assumes increased fatness at larger weights for height, which can lead to inaccuracies where increased weight is not due to increased fat mass (Moore and Diez Roux, 2006;

Table 4
Comparison of model fit between percent body fat, BMI z-score, and waist circumference.

Model	Percent body fat (DXA)				BMI z-score				Waist circumference			
	Male		Female		Male		Female		Male		Female	
	R^2	ΔR^2[d]	R^2	ΔR^2[d]	R^2	ΔR^2[d]	R^2	ΔR^2[d]	R^2	ΔR^2[d]	R^2	ΔR^2[d]
a) Individual[a]	0.20		0.06		0.01		0.04		0.27		0.34	
b) Individual & socio-cultural characteristics[b]	0.21	0.01	0.07	0.01	0.02	0.01	0.06	0.02	0.27	0.00	0.34	0.00
c) Individual, socio-cultural characteristics, & built environment[c]	0.28	0.07	0.13	0.06	0.08	0.06	0.09	0.03	0.32	0.05	0.37	0.03

[a] Adjusted for age and Tanner stage.
[b] Adjusted for age, Tanner stage, median Hispanic household income, & linguistic isolation.
[c] Adjusted for age, Tanner stage, supermarkets, restaurants, junctions, park acres, median Hispanic household income, linguistic isolation.
[d] ΔR^2 estimates for model B are in comparison to model A, estimates for model C are in comparison to model B.

Sloane et al., 2003). Among children, corrections for age and sex must also be applied, compounding the inaccuracies in the resulting BMI percentiles or BMI z-scores (Freedman and Sherry, 2009). Waist circumference is reasonably low cost and minimally invasive. Studies also find it equally as effective in predicting risk as body fat measured by DXA (Flegal et al., 2009). However, WC reproducibility depends heavily on the data collectors' skills (Wang et al., 2003). Furthermore, there are multiple accepted protocols for measuring WC, and studies have found site of measurement of WC impacts its reliability and predictive value (Bosy-Westphal et al., 2010; Hitze et al., 2008). The added precision of measuring adiposity with DXA resulted in the detection of more subtle effects of the neighborhood environment. The additional cost and logistics of DXA may preclude its use in large-scale studies, but findings suggest that there are relative gains to using a more accurate measure of body fat in the investigation of the role of the built environment on obesity.

This study presents several contributions to obesity and built environment research including the simultaneous investigation of food environment and physical activity environment, focus on a high-risk population, and the use of DXA to characterize adiposity. Despite these contributions there are limitations to consider. First, the use of cross-sectional analyses precludes the establishment of causal relationships between the built environment exposures studied here and adiposity. Second, the modifiable areal unit problem (MAUP) presents a concern, as it does with all research using spatially referenced data, where analytic results can be affected by zoning scheme or geographic scale of the areal units used. The MAUP can be minimized by using the most relevant geographic scale for the processes being studied (Kwan, 2012a; Kwan, 2012b). In this study, Census tracts were chosen to represent this geography for neighborhood-socio cultural characteristics as they were conceptualized as the broader social context in which these youths' encounters with the built environment were occurring. Third, while ego-centric buffers have been shown to more accurately measure spatial accessibility than administrative boundaries (Duncan et al., 2014b), both methods are still vulnerable to the uncertain geographic context problem (UGCoP). The UGCoP arises because the precise spatial and temporal configuration of people's true geographic context cannot be completely and accurately defined (Kwan, 2012a; Kwan, 2012b). For example, when the youth in this sample travel to school, the built environment in and around the school has not been characterized. Recent research has employed GPS technology to overcome this problem (Kwan, 2012a), and this technology may be used in future research to expand on this study's findings. And finally, the study sample only contained overweight and obese youth. Therefore findings from this study may have limited generalizability to normal weight youth.

However, these findings emphasize how persistent the impact of the built environment is to obesity, even among youth at the highest levels of risk. This analysis is also the only comparative investigation of multiple parameters for adiposity in the area of obesity and the built environment. Further research using a representative sample could enhance our understanding of the impact of the built environment on obesity. These efforts would provide stronger evidence to improve policy making and promote more effective interventions to reverse the epidemic of obesity and overweight in the U.S. and potentially world-wide.

Conflict of interest statement

The authors declare that there are no conflicts of interest.

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