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Physical Environmental Correlates of Childhood Obesity: A Systematic Review

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Abstract

Increasing rates of childhood obesity in the U.S. and other Western countries are cause for serious public health concern. Neighborhood and community environments are thought to play a contributing role in the development of obesity among youth, but it is not well understood which types of physical environmental characteristics have the most potential to influence obesity outcomes. This paper reports the results of a systematic review of quantitative research examining built and biophysical environmental variables associated with obesity in children and adolescents through physical activity. Literature searches in PubMed, PsychInfo, and Geobase were conducted. Fifteen quantitative studies met the inclusion criteria for this systematic review. The majority of studies were cross-sectional and published after 2005. Overall, few consistent findings emerged. For children, associations between physical environmental variables and obesity differed by gender, age, socioeconomic status, population density, and whether reports were made by the parent or child. Access to equipment and facilities, neighborhood pattern (e.g., rural, exurban, suburban), and urban sprawl were associated with obesity outcomes in adolescents. For most environmental variables considered, strong empirical evidence is not yet available. Conceptual gaps, methodological limitations, and future research directions are discussed.

Keywords

Environment; Overweight; Obesity; Children; Adolescents

Introduction

The dramatic rise in rates of overweight and obesity among children and adolescents over the past thirty years has ignited serious public health concern. Whereas in the early 1970s, approximately 15% of youth ages 2-19 years were considered at risk of overweight or overweight (at or above the 85th percentile of the sex-specific body mass index [BMI] on age growth charts) (1), the prevalence of overweight risk and overweight in children and adolescents increased to approximately 32% by 2003-2006 (2). Elevated rates of overweight in youth have significant health consequences including increased risk of developing type 2 diabetes, cardiovascular complications and other physical and psychological problems (3).

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Overweight children are also much more likely than normal weight children to become overweight adults (4). Gaining a better understanding of the causes and correlates of childhood obesity is an important precursor to public health efforts aimed at reversing these disconcerting trends.

A number of potential explanations have been proposed to account for the growing problem of childhood obesity in the U.S. Although genetic factors are thought to play a role in obesity susceptibility (5), a substantial change in the gene pool is unlikely to explain the upsurge in obesity seen over the past few decades (6). Instead, decreased physical activity is believed to account for much of the obesity problem. These behavioral trends have been attributed to characteristics neighborhood and community environments that favor inactive forms of leisure and transportation (7-10). In recent years, a growing body of research has documented the association between environmental features and physical activity in children and adolescents. A review conducted by Davison and Lawson (11) found that factors such as access to recreational facilities and schools, the presence of sidewalks and controlled intersections, and access to destinations and public transportation were associated with physical activity in youth. A second review paper reported that home and school environments were associated with activity levels in children, whereas low neighborhood crime incidence was associated with physical activity in adolescents (12). Other recent work suggests that the proportion of green space (13), number of cars (14), number of accessible destinations (15), and safety (16) contribute to children's and adolescent's physical activity. Overall, research suggests that aspects of the physical environment can shape behaviors related to obesity in young people.

A smaller body of work has offered support for the association between the physical environment and obesity outcomes in children and adolescents. Given the fact that body composition and overweight status can be viewed as more proximal indicators of health risk than physical activity behavior, it is important to understand whether the built and biophysical environment influences obesity outcomes in addition to obesity-related behaviors. A review conducted by Booth and colleagues (17) examines the impact of the built environment on obesity, but this paper does not focus specifically on youth. Sallis and Glanz (18) offer a nonsystematic review on the association between built environmental factors and obesity in children and adolescents. A recent review conducted by Papas and colleagues (19) also summarizes research on the built environment and obesity outcomes in adults and youth. However, this paper only considered studies using direct measures of body weight and objective assessments of the built environment. Since the time of this publication, a substantial number of new research articles on the topic have appeared.

In this paper, we provide a systematic review of quantitative research examining built and biophysical environmental influences on overweight and obesity in children and adolescents. We specifically focus on those built and biophysical environment variables thought to influence obesity-related outcomes through physical activity. A review of this emerging literature will be particularly important in guiding future research and policy, including the definition of hypotheses and specification of methodology.

Methods for Systematic Review

Search strategies and procedures

Relevant quantitative studies examining the relationship between built and biophysical environment and childhood obesity were identified through literature searches using PubMed, PsychInfo, and Geobase. Searches consisted of at least one of the following one of the following environment terms: physical environment, built environment, perceived environment, natural environment, population density, land use, street connectivity, neighborhoods, urban design, urban sprawl, urban form, air quality, pollution, trails, traffic, altitude, vegetation, or weather and one of the following obesity-related terms: obesity, overweight, body fat, body composition, Body Mass Index (BMI), body weight, body shape, waist circumference, skinfold, or waist to hip ratio. All combinations of pairs (consisting of obesity and environment terms) were searched.

Inclusion/exclusion criteria

In order to be included in the current systematic review, studies needed to 1) measure one or more features of built or biophysical environments; 2) measure BMI, overweight, or obesity; (3) be quantitative and analytic in approach; 4) report separate results for youth (ages 0-18 years); 5) be written in English; and 6) be published in a peer-reviewed journal before May 31, 2008. Studies were excluded that only examined features of the home and/or school environments, assessed built environmental characteristics through to influence obesity through food consumption (e.g., fast food restaurants, food stores), and/or measured social environmental variables (e.g., crime, safety, neighborhood socioeconomic status, neighborhood stress, neighborhood demoralization, collective efficacy, social capital, and population size or density). Studies considering traffic and road safety were included in the review because these variables more closely reflect physical environmental features (e.g., street design, traffic calming devices).

Data analyses

The initial research strategy was to perform a meta-analysis. However, after inspection of the studies, it became clear that such an analysis was not possible given the large number of environmental variables studied, inconsistency in measurement approaches and methodology, and heterogeneity in samples. Therefore, a *systematic review* was conducted using the semiquantitative procedure offered by Sallis and colleagues (20) and subsequently used in reviews conducted by Gorely and colleagues (21) and Ferreira and colleagues (12). Characteristics of each study including research design, sample characteristics, measurement strategies (perceived or objective, parent or child report), and consideration of other variables (covariates, mediators, and moderators) are presented in Table 1.

Categorization of built and biophysical environmental variables

A modified version of Lynch's lexicon of urban form elements (22) as applied to the shaping of human activity patterns (23) was used to classify potential physical environmental correlates of obesity in children and adolescents (see Tables 2 and 3). Environmental variables were divided according to their level of scale (i.e., *micro-urban* [neighborhood or community], *meso-urban* [sub-area of a city], or *macro-urban* [whole city or region]) based on Lynch's conceptual framework. Variables falling into the micro-urban category were further classified according to Lynch's urban form elements (22) (i.e., *districts, paths, nodes, edges, landmarks*).

Coding associations with obesity outcomes

The key findings pertaining to the relationship between the physical environment and the obesity outcome were coded and reported separately for children (ages 0 – 12 years) (See Table 2) and adolescents (ages 13 – 18 years) (See Table 3). The direction of associations (i.e., significant positive ($p < .05$) [+], significant negative ($p < .05$) [−]) and non-significant ($p \geq .05$) (NS) were indicated. When stratified results were provided for, separate coding and reporting was done for each analysis. Due to the small number of studies for each type of environmental variable, final association coding (i.e., summarizing across all studies) was not appropriate.

Results

General characteristics of studies

Fifteen studies met the inclusion criteria specified for this systematic review (See Table 1). Eighty percent of these (n = 12) articles were published after Jan. 1, 2006. Seven studies reported results for children (ages 3 – 12 years), seven studies focused on adolescents (ages 13-18 years), and one study included children and adolescents (ages 3-18 years) (24). Since the mean age in the Liu and colleagues (24) study was 8 years old, the results were reported as for children. Sixty percent of the articles (n = 9) included a sample of more that 1000 participants. Of the types of study designs, eighty-six percent of the studies (n = 13) were cross-sectional only, one included cross-sectional and longitudinal samples, and one was quasi-experimental. Environmental variables were measured objectively (e.g., through GIS, environmental audit) in sixty percent of the studies (n = 9) and subjectively (i.e., perceived features) in the remaining 6 studies. Of the studies assessing environmental variables subjectively, over 50% were based on child report. Seventy three percent of the studies (n = 11) included in this review used an objective measure of obesity (e.g., stadiometer, scale), whereas the remaining studies relied on self-report of height and weight.

Built and biophysical environmental correlates of obesity in children (Table 2)

Associations between micro-urban characteristics and BMI and/or obesity in children differed across demographic groups and geographical factors. Studies examining environmental features of *districts* showed that vegetation and the presence of hazards (e.g., litter, trash, noise) were correlated with obesity in this age group. Vegetation density assessed through satellite imagery was negatively associated with BMI in high but not low population density areas (24). Among children classified as coming from low socioeconomic status families, reporting a greater number of neighborhood hazards was associated with having a lower BMI. However, there was no relationship between these types of hazards and BMI for children of higher socioeconomic status (25). The associations between *path* characteristics and obesity varied to some extent by the sex and age of the children. Intersection density was negatively related to obesity for girls (26), and parent-reported road safety was negatively related to obesity in older children (10-12 years of age) (27). Other features of paths such as the availability of crossing lights and walks and public transportation (27) were not associated with BMI in children.

A few types of nodes, edges and meso-urban characteristics were related to BMI and/or obesity in children, but the mode of assessment seemed to be important for these features. Among *nodes* examined, the number of locked schoolyards was positively related to obesity in children (28). Obesity was negatively related to child-reported (29) but not parent-reported (27) access to physical activity facilities and availability of bicycle and walking trails. Other nodes such as proximity to playgrounds, parks, and play areas (27, 30); facility access (e.g., institutional, dining, leisure) (26), and access to destinations (e.g., friends' houses, shops) (27) were unrelated to BMI in children. Although *edges* such as heavy traffic (parent-reported) were positively associated with obesity in older children, there was no relationship between traffic and obesity in younger children (27). Linkages between *landmarks* and BMI in children were not evaluated. *Meso-urban* characteristics such as housing density and land use mix were unrelated to BMI (26). Objectively determined walkability was associated with BMI in girls but not boys in one study (26) and unrelated to obesity in a study using parent-reported environmental measures (31).

Built and biophysical environment correlates of obesity in adolescents (Table 3)

Of the findings for the *micro-urban* built environment, 7% of the associations were statistically significant in adolescents. Characteristics of *districts* were not examined in terms of their relationships with obesity in this age group. Studies considering *path* characteristics found that intersection density (32, 33) was unrelated to adolescent obesity. In terms of *nodes*, greater equipment accessibility (34) and the number of physical activity and recreational facilities nearby (35) were associated with lower rates of obesity. In contrast, the number of and/or distance to schools, private recreational facilities, parks (32,33) and the presence of parks or gyms (36) were not correlated with BMI. Relationships of obesity with *edges* and *landmarks* were not assessed in adolescents.

Neighborhood pattern was the only meso-urban characteristic associated with BMI (37). Adolescents living in rural, exurban, and mixed urban were more likely to be overweight than individuals living in newer suburban, older suburban, and inner city areas. Other meso-urban features such as walkability, retail floor area, land use mix and residential density were unrelated to obesity in adolescents (32,33). Results for the role of county-level sprawl differed by type of study design (38). When examined cross-sectionally, county-level sprawl was positively related to obesity outcomes. However, this relationship did not persist when tested through a longitudinal design. Climatic factors such as the average annual number of heating-degree and cooling-degrees days relative to a base temperature of 65° F were unrelated to obesity in children in cross-sectional analyses (38).

Discussion

This review summarizes research examining built and biophysical environmental variables associated with obesity in children and adolescents. Studies represented a broad range of study populations, designs, measures and outcomes. Consequently there was a lack of repetition across studies and few consistent findings emerged. For children, associations between physical environmental variables and obesity differed by gender, age, socioeconomic status, and population density. Access to equipment and facilities, neighborhood pattern, and urban sprawl were associated with obesity outcomes in adolescents. For most environmental variables considered, strong empirical evidence is not yet available. Yet, the large number of participants in many of the individual studies gives some confidence to the initial associations found. Further studies on this topic are needed to fully understand the extent to which built and biophysical environments may influence obesity outcomes in children and adolescents.

An important strength of this review was the inclusion of studies that used objective (e.g., geographic data, GIS mapping) and subjective (i.e., parent- or child-reported) assessments of physical environmental variables and obesity outcomes. Among children, findings did not differ according to whether built or biophysical environmental variables were measured objectively or through self-report. However, for the availability of physical activity facilities and access to biking and walking trails, significant associations were found for studies using child- versus parent-report. Only one study targeting adolescents measured perceptions of environmental features. Adolescent studies yielding significant findings tended to use self-reported height and weight to calculate BMI.

Methodological challenges

This review uncovered several methodological limitations evident in this literature, which if addressed in future studies, will allow for comparability of findings and stronger conclusions about the influence of the built environment on BMI/obesity in children. First, the studies in this literature predominantly used cross-sectional research designs, complicating efforts to draw causal conclusions about the effects of the built environment on BMI/obesity in children and adolescents. Future research studies should conduct opportunistic evaluations of environmental modifications (i.e., natural experiments), which can provide an opportunity to examine changes in BMI/obesity occurring in conjunction with changes in the built environment (39).

Second, there is considerable variation in the definition of built and biophysical environmental variables. Walkability measures for example use a wide range of indicators that make up an index, which varies between studies. In the study conducted by Spence and colleagues (26), this composite walkability measure included intersection density, dwelling, density and land use mix. However, the walkability index used by Merchant and colleagues (31) consisted of a slightly different set of variables including population density, street connectivity, land use mix, pedestrian supportive infrastructure/facilities, and aesthetics. Some studies test these walkability factors separately (33), whereas others only use the entire index. Bodea and colleagues (40) caution against the use of environmental indices because the results can be difficult to interpret, and the analyses are sensitive to missing data.

Third, there is little consistency across studies in the geographical boundary or size of area used for defining and exploring the influence of built environmental variables. Several definitions of neighborhood boundaries (.25 mile – 8.05 km circular buffers) were used, and different correlates were tested with each buffer size. To allow for repetition and comparability across studies, it may be necessary to establish population-specific appropriate and conventional neighborhood boundary sizes. For example, a study of older adolescent girls found that the mean reported easy walking distance was 14.8 minutes, which is equivalent to about a 0.75 mile buffer (41). Overall, research is needed to understand variability in appropriate neighborhood boundary size for different populations.

Fourth, the extent to which the effects of confounding variables are statically controlled varies across studies and may result in different findings based on these differences. Socioeconomic status (SES) is one important example given the likelihood that income and education level may account for apparent effects of the built environment if not properly controlled (40).

Compelling questions and directions for future studies

Future research should assess qualitative in addition to quantitative characteristics of potential physical environments thought to correlate with obesity in children. For example, aesthetic features of neighborhoods and public spaces, which have been associated with physical activity levels in adolescents and adults (42,43) could impact obesity-related behavior in children. Also, the use of outdoor play spaces among youth may be promoted by features such as shade, swings, water attractions, and cleanliness (44).

An area that deserves more research attention is the potential interdependency among various built environmental variables in their relation to obesity among youth. Available nodes (e.g., parks, recreational facilities) may be underutilized because there is a lack of sufficient paths (e.g., bike lanes, connected streets, cross walks), transport options (public or parent automobile), or barriers created by edges (e.g., major freeways, heavy traffic) on the way to those locations. Difficulty in accessing community recreational facilities was correlated with inactivity among Chinese adolescents (45), suggesting that presence/absence of facilities needs to be understood in the context of proximity and access. Future studies should jointly assess the availability of facilities and the opportunities for safe transport by walking or biking to these locations.

To further advance the field, features of the built and social environments might be combined with psychosocial variables to propose mediational models that can be tested to develop theories of how environment influences behavior (e.g., physical activity, dietary intake) and BMI/obesity (46-48). For example, self-efficacy, motivation, and social support mediated the effects of the physical environment on physical activity (49). Placing a greater emphasis on theory-oriented approach will guide empirical work in an informed way and lead to more rapid advancement of the field.

A number of authors over the last five years have noted the importance of moving this literature to a deeper analytic level by exploring the influences of one strata of the environment on other levels (27). Examined from the perspective of Social Ecological theory (50, 51), the variance in BMI/obesity that can be explained in our models may be greatly enhanced by testing interactions between different levels of contextual analysis (e.g., environmental, social, cultural, economic, political) (9). It may also be important to consider how the strength of predictors might vary by important moderating factors such as age, sex, ethnicity, and SES of neighborhood.

Limitations of the review

Due to the small number of studies available and the lack of consistent measurement, we conducted a systematic review instead of a meta-analysis. Therefore, it was not possible to calculate standardized effect sizes for the predictor variables. However, we were able to provide a descriptive summary of the findings and highlight areas for future research. In this manuscript, we have elected to limit our paper to built and biophysical environmental features conceptually linked to *physical activity*. This decision is both a strength and a limitation of the manuscript since it leaves the dietary component of the determination of BMI/obesity unexplored. Future studies should examine the diet-related built environment variables and their influence on BMI/obesity although a recent review indicated that few such studies existed (18).

Implications for intervention and policy

In order to effectively reduce the prevalence of obesity in children and adolescents, we need to identify *modifiable* and *specific* built and biophysical environmental features that are amenable to programmatic and policy intervention. Physical characteristics of school environments are relevant intervention targets due to the significant amount of time that children spend in this setting. Policies that increase playground space, improve the quality of equipment, and allow schoolyard accessibility on the weekends could be useful measures to combat childhood obesity. The weak associations of community features such as parks and recreational facilities with childhood obesity outcomes suggest that it might be necessary to enhance the *use* of these resources through promotional strategies and messages, and targeted campaigns. In fact, the Task Force on Community Preventive Services recommends that the creation and enhancement of physical activity resources should be combined with informational outreach activities (52).

Conclusions

In light of the growing obesity epidemic among children and adolescents in the U.S., we need to identify modifiable environmental factors that can be readily translated into population-level interventions and polices. A systematic review of the literature on the built and biophysical environmental and obesity in youth revealed a small but diverse number of studies representing a broad range of study populations, designs, measures and outcomes. For most of the environmental variables considered, strong empirical evidence is not yet available. Future research should strive for consistency in the types of variables, measures, buffer sizes, control variables used. Further studies should seek to better understand the impact of the qualitative environmental characteristics and consider the joint contributions of available facilities and travel routes to those locations. Also, future studies should attempt to utilize longitudinal, quasi-experimental, and experimental research designs in order to better sort out the direction of causality between environments and obesity outcomes. Lastly, mediators and moderators of the relationship between physical environments and obesity need to be explored (including interactions between different levels of the environment) in order to guide more theoretically-sound and hypothesis-driven research in this area.

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Table 1

Summary of Studies Examining the Associations of Built/Biophysical Environments with Obesity in Children and Adolescents

Authors	Type of Study (Data set)	Sample size	Age range or Mean age	Sex	Other Socio-demographic Characteristics	Assessment of Physical Environment	Geographical Boundary Size	Assessment of Obesity	Covariates/ Stratification
Burdette & Whitaker, 2004 (30)	Cross-sectional	*N* = 7,020	3-4 years	Boys and girls combined	Low-income	Objective	Not applicable	Objective	Household income, Race, Sex
Evenson, et al., 2007 (29)	Cross-sectional	*N* = 1,554	6th grade	Girls only	Residents of 6 states across the US	Perceived (child)	Not defined	Objective	Race/ethnicity, Age, School Percentage of free and reduced lunches, Neighborhood SES index
Ewing et al., 2006 (38)	Cross-sectional and Longitudinal	*N* = 6,760 (cross-sectional analysis) *N* = 3,667 (1st longitudinal analysis) *N* = 2,427 (2nd longitudinal analysis)	12-17 years	Boys and girls combined	Nationally representative sample living in metropolitan areas	Objective	County of residence	Self-report (child)	Crime rate, Climate, Age, Gender, Ethnicity, Smoking status, Hours worked, Hours TV watching, Gross Household Income, Parents' Education
Gordon-Larsen et al., 2006 (35)	Cross-sectional	*N* = 20,745	7th - 12th grade	Boys and girls combined	Nationally representative school-based sample	Objective	8.05 km circular buffer	Self-report (child)	Population density
Kligerman et al., 2006 (32)	Cross-sectional	*N* = 98	14- 17 years	Boys and girls combined	Residents of San Diego County, CA. (60% Mexican-Am.)	Objective	.25 mile, .50 mile, and 1 mile circular buffer	Objective	Gender, Ethnicity
Liu et al., 2006 (24)	Cross-sectional	*N*=7,334	3-18 years (mean age = 8 years)	Boys and girls combined	Members of a network of primary care clinics in Marion County, IN	Objective	2 km circular buffer	Objective	Population density, Neighborhood level SES, Age, Race, Gender
Merchant et al., 2007 (31)	Quasi-experimental	*N* = 156	1st – 8th grade	Boys and girls combined	Residents of Ontario, Canada.	Perceived (parent)	Not defined	Objective	Not reported
Motl et al., 2007 (34)	Cross-sectional	*N* = 1,655	Mean age = 17.7 years	Girls only	Residents of South Carolina	Perceived (child)	Not defined	Not reported	Parental education
Nelson et al., 2006 (37)	Cross-sectional	*N* = 20,745	7th – 12th grade	Boys and girls combined	Nationally representative, school-based sample	Objective	3 km circular buffer	Self-report (child)	Age, Race/ethnicity. Parent education, Income

Authors	Type of Study (Data set)	Sample size	Age range or Mean age	Sex	Other Socio-demographic Characteristics	Assessment of Physical Environment	Geographical Boundary Size	Assessment of Obesity	Covariates/ Stratification
Norman et al., 2006 (33)	Cross-sectional	*N* = 799	11-15 years	Boys and girls separately	Primary care patients	Objective	1 mile circular buffer	Objective	Age, Ethnicity, Household education level
Romero et al., 2001 (25)	Cross-sectional	*N* = 796	Mean age = 9 years	Boys and girls combined	Students from Northern CA elementary schools	Perceived (child)	Not defined	Objective	SES
Scott et al., 2006 (28)	Cross-sectional	*N* = 1,556	6^{th} grade	Girls only	Residents of 6 states across the U.S.	Objective	.50 mile circular buffer)	Objective	Race, SES, Number of parks, Number of accessible schools with active amenities, Number of locked schools, Presence of school within 1 mile buffer, Percent of students receiving free and reduced price lunch
Spence et al., 2008 (26)	Cross-sectional	*N* = 501	4-6 years	Interaction term created with gender. Boys and girls separately.	Patients at a local health center	Objective	1.5 km circular buffer	Objective	Physical activity, junk food consumption, neighborhood-level social class.
Timperio et al., 2005 (27)	Cross-sectional	*N* = 291 (sample 2) *N* = 919 (sample 1)	5-6 years (sample 1) 10-12 years (sample 2)	Boys and girls combined	Students from randomly selected schools in Australia.	Perceived (parent and child)	Not defined	Objective	Sex, SES, Family car ownership
Ward et al., 2006 (36)	Cross-sectional	*N* = 1,015	Mean age = 14.6 years	Girls only	45% African-American	Perceived (child)	Not defined	Objective	Weight group, Race/ethnicity

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Table 2

Summary of Built and Biophysical Environmental Correlates of Obesity in Children (ages 3-12 years).

Category	Feature	Positively related (+) Biblio no.	Negatively related (−) Biblio no.	Unrelated Biblio no.
1. Micro-Urban Scale				
a. Districts	Neighborhood hazards (e.g., traffic, litter, trash)		*25LSES*	*25HSES*
	Vegetation		24HD	24LD
b. Paths	Intersection density		26G	26B
	Road safety		*27O*	*27Y, 27O, 27Y*
	Crossing lights and walks			*27*
	Availability of/Access to public transportation			*27*
c. Nodes	Number of locked schoolyards	28		
	Proximity to playgrounds, parks, play areas			30, *27, 27*
	Facility access (institutional, maintenance, dining, leisure)			26G, 26B
	Access to physical activity facilities		*29*	*27*
	Availability of bicycle and walking trails		*29*	*27*
	Access to destinations (friends' houses, schools, shops)			*27*
d. Edges	Heavy traffic	*27O*		*27Y, 27O,27Y*
e. Landmarks	----			
2. Meso-Urban Scale	Walkability (e.g., population density, street connectivity, land use mix, pedestrian supportive infrastructure/facilities, aesthetics, intersection density, dwelling density)		26G	26B, *31*
	Dwelling (housing) density			26G, 26B
	Land use mix			26G, 26B
3. Macro-Urban Scale	----			

Italics = perceived environmental feature, underline = parent reported, LSES = low socioeconomic status, HSES = high socioeconomic status, Y = younger age (5-6 years), O = older age (10-12 years), HD = high population density, LD = low population density.

Table 3

Summary of Built and Biophysical Environmental Correlates of Obesity in Adolescents (ages 13-18 years).

		Positively related (+) Biblio no.	**Negatively related (−) Biblio no.**	**Unrelated Biblio no.**
1. Micro-Urban Scale				
a. Districts	---			
b. Paths	Intersection density			32,33
c. Nodes	Number of schools			32,33
	Number of physical activity and recreational facilities		35	
	Number of private recreation facilities			32,33
	Distance to nearest private recreational facility			32
	Equipment accessibility		34	
	Presence of parks and gyms			*36*
	Number of parks			32,33
	Area of parks			32
	Distance to nearest park			32
d. Edges	____			
e. Landmarks	____			
2. Meso-Urban Scale	Neighborhood pattern (Rural, exurban, mixed urban vs. newer suburban, older suburban, inner city)	37		
	Walkability index (land use mix, retail density, street connectivity ,residential density)			32
	Retail floor area ratio			32,33
	Land use mix			32,33
	Residential density			32,33
3. Macro-Urban Scale	County sprawl index		38CS	38L
	Number of heating and cooling days			38CS

Italics = perceived environmental feature, CS = Cross-sectional. L= Longitudinal.