ABSTRACT

Title of thesis: INVESTIGATING NEIGHBORHOOD WALKABILITY AND ITS ASSOCIATION WITH PHYSICAL ACTIVITY LEVELS AND BODY COMPOSITION OF A SAMPLE OF MARYLAND ADOLESCENT GIRLS

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Introduction: Recent ecologic studies have begun to focus on characteristics of the built environment that influence physical activity (PA). Specifically, neighborhood walkability is emerging as an important determinant of PA in adults. At this point in time, there is conflicting evidence on how neighborhood walkability influences the PA levels of adolescents. Objective: To investigate the relationship between individual's neighborhood walk score and individual's body mass index, body fat percentage, weight status, PA levels and meeting PA guidelines in a sample of adolescent girls. Additional analysis investigated the correlation between two objective measures of neighborhood walkability. Methods: Mixed linear regression was used to examine the associations between neighborhood walkability and PA levels and body composition measures. Mixed logistic regression was used to examine the association between neighborhood walkability and odds of meeting PA recommendations and normal weight. Pearson correlation coefficient was used to analyze the association between a GIS derived walkability index and neighborhood walk score as calculated by website: www.walkscore.com. Results: This analysis was unable to show an association between PA levels or body composition of adolescent girls from the TAAG Maryland field site. Neighborhood walkability as assessed by the website walkscore.com was positively correlated with a GIS derived walkability index ($r=.63$ $p<.0001$).

INVESTIGATING NEIGHBORHOOD WALKABILITY AND ITS ASSOCIATION WITH PHYSICAL ACTIVITY LEVELS AND BODY COMPOSITION OF A SAMPLE OF MARYLAND ADOLESCENT GIRLS

By

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Table of Contents

List of Tables

List of Figures

Chapter 1: Background

The Built Environment Influences on Physical Activity and Introduction to Neighborhood Walkability

The social ecologic model proposes that behavior is influenced by an interaction between personal attributes, the physical environment, and the social environment (Stokols, 1992). An important assumption in this model is that environments are multidimensional and are characterized by both physical and social components, have objective and subjective qualities, and can be scaled to the individual or to the group. Recent ecologic studies have begun to focus on characteristics of the built environment that influence physical activity (Trost, Owen, Bauman, Sallis & Brown, 2002). Cross sectional studies show that access to recreation centers such as tracks, golf courses, parks and swimming pools are important determinants for adults participating in physical activity (Booth, Owen, Bauman, Clavisi & Leslie, 2000). An international study of adults age 18-65 found that individuals living in neighborhoods with attributes of shops near home, transit stop near home, sidewalks present, facilities to bicycle to or low-cost recreation facilities were all more likely to engage in higher levels of physical activity (Sallis et al., 2009). Furthermore, studies have also found that environmental variables of neighborhood terrain, scenery, presence of unattended dogs, and observing others exercise in the neighborhood are also factors that influence physical activity (King, Wilcox, Eyler, Sallis & Brownson, 2000).

Another emerging trend when studying health and the built environment is exploring the effect of neighborhood walkability and physical activity levels. Neighborhood walkability is typically defined either objectively by using geographic information systems (GIS) technology to create a continuous score/index or subjectively by assessing the perceptions of neighborhood features that encourage physical activity such as road connectivity, ease of access, and presence of sidewalk. More specifically, studies with objectively defined measures tend to use similar categories of net residential density, land mix use, intersection density and net retail area to create a walkability index for a particular unit of geographical measurement (Leslie et al., 2005; Van Dyck et al., 2009; Sallis et al., 2009; Frank, Schmid, Sallis, Chapman & Saelens, 2005; Kligerman, Sallis, Ryan, Frank & Nader, 2007).

Neighborhood Walkability and Adolescents

Presently, studies of neighborhood walkability and physical activity in adolescents are limited and lack consistency. A study conducted in the US found adolescents in walkable neighborhoods have higher levels of physical activity compared to adolescents living in less walkable neighborhoods (Kligerman, Sallis, Ryan, Frank & Nader, 2007). Meanwhile, a study of Belgian adolescents found that a less walkable community, defined as low street connectivity and low population density measures, was associated with higher levels of physical activity (Van Dyck, Cardon, Deforche & Bourdeaudhuij, 2009). Studies have also found inconsistent relationships between adolescents body mass index (BMI;kg/m^2) and neighborhood walkability. Kligerman et al. (2007) reported no association between BMI and neighborhood walkability while Nelson, Gordon-Larsen, Song & Popkin (2006) found that adolescents who lived in Neighborhoods with low street connectivity were about 30% more likely to be classified as BMI$\geq 95^{th}$ percentile of age and gender-specific national growth curves when controlling for socio-economic-status (SES), age, and race/ethnicity. Measuring subjectively, Evenson, Scott, Cohen & Voorhees, (2007) found that neighborhood factors such as seeing walkers and bikers pass by, low crime, seeing others play outdoors, bike and walk trails in the neighborhood and access to physical activity facilities are all associated with lower BMI in adolescent girls. Aside from inconsistent associations across these studies, validity of using the objective measures of population density, connectivity, land mix, and retail density to measure the neighborhood walkability is unknown. Although these measures are commonly used, other factors that may contribute to walking in one's neighborhood such as accessibility to facilities, types of destinations, parks and transit may also be of interest to research (Leslie et al., 2007).

Introduction to GIS

Aside from the uncertainty of how neighborhood walkability impacts the health of adolescents, most objective measures of the environment use GIS technology. GIS technology is a mapping tool that is able to link spatial and non-spatial data to a specific geographic location (Tim, 1995). Although GIS is widely used in public health research, there are limitations. GIS is an expensive software package that requires a user who has been specially trained to use the product (Tim, 1995). Specific limitations for using GIS to investigate physical activity are also apparent. Broad categories of variables populated by GIS make it difficult to explain associations with physical activity (Forsyth, Schmitz, Oakes, Zimmerman & Koepp, 2006). For example, it is not known what the most appropriate measure of geographical scale may be, e.g. network/street distance buffers, census tract, or 200 meter buffer. The gold standard has not yet been identified; thus, investigations tend to use a mix of these measures, which can make comparisons across studies difficult. Along with this, defining the geographic location of "neighborhood" of an individual's environment for engaging in physical activity is also limited when using GIS technology (Saelens, Sallis, Black & Chen, 2003).   There is also uncertainty regarding which objective measures of the environment are valid and reliable variables to assess the relationship with physical activity (Forsyth et al., 2006). Using GIS may limit analysis because only variables that are accessible to the GIS database may be examined (Frank et al., 2005). Furthermore, there are often issues with data quality and availability that do not allow for proper GIS analysis (Forsyth et al., 2006). Overall, there is a need for more research in the area of investigating the associations between neighborhood walkability and physical activity levels and body composition in adolescents.

Introduction to Walkscore.com

Walkscore.com is a publicly available and free to access website that uses the distance of local amenities such as transit, grocery stores, restaurants, coffee shops, bars, movie theaters, schools, parks, libraries, bookstores, fitness facilities drug stores, hardware stores, clothing and music to calculate a walkability score of an individual address query. Amenities are based on a Google search algorithm and are therefore based on currently available resources. Scores range from 0 (lowest walkability/car dependent) to 100 (highest walkability) and each individual residence receives a score. Walkscore.com is easy to use as it has a simplistic technical design. For these reasons, there is great potential for the use of walkscore.com in public health research. A poster presented at the 2009 American Public Health Association's annual conference, Brewster, Hurtado, Olson & Yen, used walkcore.com to explore the associations between the health outcomes of obesity, hypertension and diabetes and found that higher levels of walk score were associated with lower levels of disease. To date, no studies have been published using walkscore.com as a variable of interest.

Walkscore.com may be a potentially valuable tool to objectively measure neighborhood walkability. As suggested by Leslie et al., (2007), distances to major services are likely to influence choices to make walking trips in one's neighborhood--the basis of walkscore.com. In addition the walkability index is applied to the individual residence level creating a robust measure. In particular, walkscore.com may be a good measure of the types of goods and services frequented by adolescent girls. Adolescent girls may also be more inclined to walk as a mode of travel, as they are not yet old enough to drive. For these reasons, there is a need to assess the validity of using walkscore.com to measure neighborhood walkability and its association with individual's level of physical activity.

Research Aims

The aims of this study were to determine if neighborhood walkability was associated with physical activity levels and body composition of a sample of adolescent girls. A secondary aim was to examine the relationship between two walkability scores; a GIS derived index and walkscore.com. We hypothesize the following: 1) those that live in neighborhoods with high walk scores will have higher levels of physical activity than those that live in neighborhoods with low walk scores 2) those that live in neighborhoods with high walk scores will be more likely to meet physical activity guidelines 3) those that live in neighborhoods with high walk scores will have more favorable body composition and 4) those that live in neighborhoods with high walk scores will be more likely to be considered normal BMI.

Chapter 2: Methods

Study Sample

Trial of Activity for Adolescent Girls (TAAG) is a multi-center group-randomized intervention study that targeted schools, community agencies, and girls to increase physical activity in middle school girls (Webber et al., 2008). About 3,502 girls from six different field centers: the University of Arizona, San Diego State University, Tulane University, the University of Maryland, the University of Minnesota, and the University of South Carolina participated. The analytic sample of this research is specific to participants enrolled at the University of Maryland field site in spring 2006 (n=730). Public middle schools in Montgomery and Baltimore County Maryland that had a majority of students living in the surrounding community, at least 90-8th grade girls, low early withdrawal rates, at least one semester of physical education for each grade and a willingness to participate were invited to be a part of the Maryland field site for TAAG. Girls who completed individual assent and parental consent were invited to take part in TAAG measurement. Exclusion criteria for individual participation in TAAG were 1) limited English speaking skills or 2) inability to participate in physical education classes due to a medical condition or disability (Webber et al., 2008).

Secondarily, analysis was also completed to assess the correlation between a GIS derived walkability index and a neighborhood walk score retrieved from public website walkscore.com. For this analysis a sample of TAAG girls from 6th grade with self-reported home address reported in spring 2003 was used. Girls' addresses were geocoded using ArcGIS software and variables related to 1 mile buffer of: residential density, land-mix use, and street connectivity were available for use in this analysis (n=186).

Variable Descriptions

Independent Variable: Neighborhood Walkability Measurement

Neighborhood walkability was objectively measured through the use of walkscore.com. Addresses were obtained from the 730 Maryland field site participants consent forms and entered into walkscore.com search query. A continuous variable ranging from 0-100 was obtained for each participant. As previously described, walkscore.com is a publicly available website that searches for local amenities near an individual's address to create an objective measure of neighborhood walkability. Specifically, it uses as Google search algorithm to map the proximity to local amenities (e.g., restaurants, movie theaters, stores, parks, schools) in a 1 mile radius of an individual's residence; the closer the proximity to the residence, the more points are awarded to the walk score.

Dependent Variables: Physical Activity Measurement

Physical activity was objectively measured through the use of Actigraph accelerometers (Health Systems Model 7164; Manufacturing Technologies Inc, Shalimar, Fl). The accelerometer detects and records counts/30 second intervals which is then used to measure physical activity levels. Accelerometers were worn by participants for a period of seven days, except when sleeping, bathing or swimming. The average daily minutes of physical activity for different cut points of intensity: 4.6 metabolic equivalents of task and 3.0 metabolic equivalents of task (METs) was calculated. For moderate to vigorous physical activity (MVPA) corresponding to 4.6 METs, the accelerometer counts are defined as ≥1500 counts/30 seconds, while light physical activity (PA) is defined as

50-1499 counts/30seconds. This is based on a threshold that was found to have optimal sensitivity and specificity for activities specifically performed by 8th grade girls corresponding to 4.6 metabolic equivalents (Treuth et al., 2004). The 3.0 MET cut point has also been used as a more liberal estimate of physical activity in adolescents and therefore was also used in analysis in this study (Pate et al., 2006). For MVPA corresponding to 3.0 MET, the accelerometer counts are defined as ≥579 counts/30 seconds (Pate et al., 2006). The average daily minutes of 4.6 MET weighted MVPA before and after school is the sum of before school activity (6AM-school start time) and after school (school end time-6PM).

Both MET weighted and unweighted average daily minutes of MVPA were assessed. A regression equation, MET=2.01+0.00171 × (counts/30 sec) was used to calculate the MET energy expenditure based on the 30 second accelerometer count (Treuth et al., 2004). The counts meeting the minimum MVPA threshold are inserted into the equation and the products for each 30 second interval are summed to create the total MET weighted minutes of MVPA over the entire day. In general, the MET weighted minutes of MVPA accounts for intensity, while unweighted does not. When unweighted, credit is simply awarded for reaching counts over the MVPA threshold (1500 for 4.6 MET cut point, 579 for 3.0 MET cut point) and thus there would be no difference between someone who has engaged in a two minute brisk walk versus someone who had engaged in a two minute sprint. See Figure 1 for an example of how the same participant's daily minutes MET weighted and unweighted MVPA would be calculated depending on the 3.0 or 4.6 MET cut point used.

The average daily minutes of 4.6 MET-weighted MVPA was the primary measure of physical activity in this analysis but we assessed the following other cut points of intensity:

- Average daily minutes of 4.6 MET unweighted MVPA
- Average daily minutes of 3.0 MET weighted MVPA
- Average daily minutes of 3.0 MET unweighted MVPA
- Average daily minutes of 4.6 MET unweighted light physical activity
- Average daily minutes of 4.6 MET weighted MVPA before and after school

Figure 1. Example of 3.0 [1]MET and 4.6 [1]MET Weighted & Unweighted [2]MVPA Measurement Calculation Based on Accelerometer Counts/30 seconds

Time	Accelerometer Count	3.0 [1]MET unweighted [2]MVPA (minutes)	4.6 [1]MET unweighted [2]MVPA (minutes)	3.0 [1]MET weighted [2]MVPA (MET weighted minutes)	4.6 [1]MET weighted [2]MVPA (MET weighted minutes)
0:30	1000	0.5	0	3.71	0
1:00	1500	0.5	0.5	4.56	4.56
1:30	1700	0.5	0.5	4.9	4.9
2:00	3000	0.5	0.5	7.11	7.11
2:30	1000	0.5	0	3.71	0
Total		2.5 mins	1.5 mins	23.99 MET weighted mins	16.57 MET weighted mins
Minimum 30 second count for MVPA: 579 counts/30 seconds or greater, 3.0 [1]MET; 1500 counts/30 seconds or greater, 4.6 [1]MET. [1]MET =2.01 + 0.0017×(counts/30 seconds)					

[1]MET= Metabolic equivalent of task.
[2]MVPA= Moderate-to-vigorous physical activity.

Dependent Variables: Body Composition Measurements

Height, weight and tricep skinfold thickness were collected by trained data collectors. Standing height was measured two times to the nearest 0.1 cm using a portable stadiometer (Shorr Productions). Weight was measured two times to the nearest 0.1 kg using a digital scale (Seca 880). The averaged height and weight measures were used to calculate BMI (weight in kilograms/ height in meters^2). Tricep skinfold thickness was measured to the nearest 0.1 mm, three measurements were taken and the average measurement was inserted into an equation: DXA percent fat = −23.39 + 2.27 (BMI) + 1.94 (Triceps skinfold, mm) − 2.95(race) − 0.52 (Age in years) − 0.06 (BMI x Triceps skinfold,mm) to estimate percent body fat (Loftin et al., 2007).

Covariates

Other variables race, free and reduced lunch status, and mother's highest educational attainment were collected as part of a student survey. Demographic variables were self-reported by participants. Race variables were categorized as Non-Hispanic White, Non-Hispanic Black, Hispanic or Non-Hispanic other. Mother's highest educational attainment was categorized as high school or less (including vocational school), college/some college, or professional degree beyond college. Treatment or control was also accounted for in all analysis as participants were part of a randomized intervention study.

GIS Derived Variables

Within the literature, neighborhood walkability index is calculated by the formula: *Walkability = [(2 x z-intersection density) + (z-net residential density) + (z-land* *use mix + (z-retail floor area ratio)]* (Frank et al., 2009). The GIS derived variables available within the TAAG dataset to represent these measures were: Alpha, beta and gamma measures of street connectivity within a 1-mile circular buffer of a residence combined to a single factor (intersection density), number of households per square mile within a 1-mile circular buffer of a residence (residential density), land use/land cover diversity index within a 1-mile circular buffer of a residence (land mix use). No measure for retail floor area ratio was available, so this was not included for in this analysis. Further information on each of these measures is described below:

Intersection Density: Street centerline data from the US Census Bureau (TIGER) were used to create three connectivity indices for each girl's 1-mile circular buffer of residence. Alpha, beta and gamma indices were combined to measure the ratio of intersections to street segments using previous methodology published by Cohen et al., (2006). Briefly, the alpha index is a ratio representing the number of loops given the number of circuits in a tract, beta is the ratio of streets per node, and gamma is the number of intersections within a tract. Higher values indicate greater connectivity. (Cohen et al., 2006).

Residential Density: The number of households per square mile was calculated using data from the 2000 Census.

Land Mix Use: Land mix use was calculated using the national land use and land cover classified satellite imagery. Specifically, a dissimilarity index is computed for each neighborhood representing the proportion of mixed land-uses among a grid of cells in the

1-mile buffer. This is expressed on a scale of 0 to 1, higher values representing greater diversity (Voorhees et al., In Press).

Statistical Analysis

Descriptive statistics (means and frequencies) were used to summarize characteristics of the TAAG Maryland field site participants and to summarize main independent variables and dependent variables. For additional descriptive purposes, a categorical variable for neighborhood walk score was created using the quartile distribution of the continuous variable walk score. Mean BMI, body fat percentage, and physical activity levels were calculated for each quartile of walkability. The variables BMI and daily minutes of physical activity were skewed so the natural log transformation was used in regression analysis requiring these continuous variables. Pearson correlation coefficients between neighborhood walkability score and BMI, percent body fat, and all average daily physical activity variables were computed. All analyses adjusted for the clustered study design using mixed linear models for continuous variables and mixed logistic regression models for dichotomous dependent variables (PROC MIXED and PROC GLIMMIXED in SAS version 9.1 SAS Institute Inc, Cary, NC). To determine if neighborhood walkability is associated with physical activity levels and body composition, mixed linear regression models were conducted using neighborhood walk score as the independent variable. Seven separate models were run for each dependent variable. Neighborhood walk score was the independent variable and the following were treated as the dependent variable: average daily minutes of 4.6 MET-weighted MVPA, average daily minutes of 4.6 MET unweighted MVPA, of 3.0 MET-weighted MVPA, average daily minutes of 3.0 MET unweighted MVPA, average daily minutes of 4.6 MET light activity, average daily minutes of 4.6 MET weighted MVPA before and after school, BMI, and percent body fat. Additionally, a mixed logistic regression model was conducted to determine the association between meeting physical activity recommendations of 60 minutes of MVPA (Strong et al., 2005) and overweight/obesity status (determined by BMI) based on the independent variable: neighborhood walk score. Since so few girls met the set recommendation levels at the 4.6 MET cut point, an additional cut point of average daily minutes of 3.0 MET weighted MVPA was also modeled in the mixed logistic regression (see Table 6). All models controlled for the following variables: race/ethnicity, mother's highest educational attainment, free and reduced lunch status, school site, and intervention/control group. For all analysis significance was set at p=0.05.

Although the primary goal of this analysis was to determine if neighborhood walk score is associated with physical activity levels and body composition, a secondary aim was to investigate the correlation between neighborhood walkability (as assessed through walkscore.com) and a GIS derived walkability index. A GIS index was derived by normalizing each variable of street connectivity, land use and net residential density by the use of z-scores: *Walkability = [(2 x z-intersection density) + (z-net residential density) + (z-land use mix)].* Intersection density was weighted by a factor of two based on recommendations from other GIS derived indices of walkability found in the literature (Frank et al., 2009). Pearson partial correlation coefficients were then calculated between walkscore.com and a GIS derived index. Significance level was again set at p=0.05.

Independent sample t-test and chi square tests were conducted to compare the characteristics of the 186 (spring 2003) participants to the 730 (spring 2006) participants.

Chapter 3: Results

The 730 girls in this study were highly diverse, with less than ½ non-Hispanic White, and approximately ¼ each non-Hispanic Black or Hispanic. Sample characteristics are found in Table 1. The mean neighborhood walk score from walkscore.com was 42.15, which was normally distributed with a range from 0 to 98. The mean BMI was 22.61 kg/m^2 and the mean percent body fat of the sample was 31. About one-third of the sample was considered as at risk for overweight or overweight, with their BMI >85^{th} percentile. Data on physical activity were available for 727 subjects. The average daily minutes of MET-weighted MVPA for the sample was 127 minutes. Descriptive statistics of additional physical activity measurements can be found in Table 1.

Table 1. Descriptive Statistics for Trial of Activity for Adolescent Girls Maryland Field Site

Measure	n	Mean or %	SD	Range
Walk Score	730	42.15	22.39	0-98.00
[1]BMI	730	22.61	5.18	13.27-47.47
Percent Body Fat	729	31.04	8.80	7.74-52.43
[2]Avg daily min 4.6 MET weighted MVPA	727	126.68	67.67	16.30-479.18
[3]Avg daily min of 4.6 MET unweighted MVPA	727	21.25	10.66	2.87-82.51
[4]Avg daily minutes of 3.0 MET weighted MVPA	727	354.94	114.85	123.25-956.62
[5]Avg daily min of 3.0 MET unweighted MVPA	727	84.56	24.77	29.40-210.70
[6]Avg daily minutes of light PA	727	301.91	53.60	160.43-515.82
[7]Avg daily minutes of 4.6 MET weighted MVPA, before & after school		80.74	190.03	6.25-3722.33
Race/ethnicity				
White	318	43.56%		
Black	169	23.15%		
Other	140	19.18%		
Hispanic	103	14.11%		
***Mother's** Education*				
High school or Less	186	25.48%		
College/Some college	253	34.66%		
Professional training and beyond college	147	20.14%		
Unknown	144	19.73%		
Free and Reduced Lunch Status				
Free and reduced lunch Yes	208	28.49%		
Free and reduced lunch No	479	65.62%		
Free and reduced lunch unknown	43	5.89%		

[1]BMI= Body mass index (weight kg/ height m^2).
[2]PA Cut point 1= 4.6 Metabolic equivalent of task weighted moderate-to-vigorous physical activity.
[3]PA Cut point 2= 4.6 Metabolic equivalent of task unweighted moderate-to-vigorous physical activity.
[4]PA Cut point 3= 3.0 Metabolic equivalent of task weighted moderate-to-vigorous physical activity.
[5]PA Cut point 4= 3.0 Metabolic equivalent of task unweighted moderate-to-vigorous physical activity.
[6]PA Cut point 5= 4.6 Metabolic equivalent of task unweighted light physical activity.
[7]PA Cut point 6= 4.6 Metabolic equivalent of task weighted moderate-to-vigorous physical activity, before and after school.

Table 2 displays the quartile distribution of mean body composition and physical activity levels for each quartile of neighborhood walk score. BMI and percent body fat did not differ across walk score categories. There also was no difference in physical activity across categories, irrespective of the method in which MVPA was defined.

Results from correlation analyses between walk score and continuous variables (e.g., BMI, percent body fat and physical activity) did not reveal any significant associations (Table 3). Pearson correlations were below the magnitude of R = 0.10 (ns).

Table 2. Pearson Correlation Coefficient Among Dependent Variables with Neighborhood Walk Score

Variable	R (Pearson Correlation Coefficient)	p-value
[1]BMI	0.05	0.14
Percent Body Fat	0.004	0.90
[2]4.6 MET weighted MVPA	0.03	0.37
[3]4.6 MET unweighted MVPA	0.05	0.19
[4]3.0 MET weighted MVPA	0.04	0.27
[5]3.0 MET unweighted MVPA	0.05	0.17
[6]4.6 MET unweighted Light PA	0.03	0.36
[7]4.6 MET weighted MVPA, before and after school	-0.04	0.23

[1]BMI= Body mass index (weight kg/ height m^2).
[2]4.6 Metabolic equivalent of task weighted moderate-to-vigorous physical activity.
[3]4.6 Metabolic equivalent of task unweighted moderate-to-vigorous physical activity.
[4]3.0 Metabolic equivalent of task weighted moderate-to-vigorous physical activity.
[5]3.0 Metabolic equivalent of task unweighted moderate-to-vigorous physical activity.
[6]4.6 Metabolic equivalent of task unweighted light physical activity.
[7]4.6 Metabolic equivalent of task weighted moderate-to-vigorous physical activity, before and after school.

The results obtained from multivariate linear regression for log BMI and percent body fat is reported in Table 4. No association was found between walk score and body composition. Controlling for the covariates, the beta coefficient approached zero, with high p-values.

Table 3. Quartiles of Neighborhood Walk Score and Selected Dependent Variables

					Mean Average Daily Minutes of Selected Physical Activity Cut Points (Standard Deviation)					
Quartile	Walk Score range	n	[1]BMI	[2]% Body Fat	[3]PA Cut point 1	[4]PA Cut point 2	[5]PA Cut point 3	[6]PA Cut point 4	[7]PA Cut point 5	[8]PA Cut point 6
1 (lowest)	0-25	192	21.89 (4.19)	30.91 (4.20)	127.41 (76.14)	21.10 (11.95)	350.07 (129.82)	82.84 (27.57)	296.39 (52.87)	84.16 (269.85)
2	26-42	167	22.52 (5.16)	30.30 (9.01)	126.22 (64.33)	21.04 (9.71)	356.74 (107.13)	85.06 (23.17)	306.11 (56.11)	100.19 (261.65)
3	43-60	202	23.77 (5.81)	32.77 (8.77)	123.00 (61.64)	20.78 (9.84)	351.52 (108.35)	84.14 (23.92)	303.09 (57.62)	71.00 (59.22)
4 (highest)	61-100	169	22.12 (5.24)	29.85 (9.37)	130.79 (67.89)	22.23 (10.99)	362.93 (112.12)	86.56 (23.98)	302.63 (46.25)	69.60 (45.46)

[1]BMI= Body mass index (weight kg/ height m^2).

[2]% Body Fat= Percent body fat.

[3]PA Cut point 1= 4.6 Metabolic equivalent of task weighted moderate-to-vigorous physical activity.

[4]PA Cut point 2= 4.6 Metabolic equivalent of task unweighted moderate-to-vigorous physical activity.

[5]PA Cut point 3= 3.0 Metabolic equivalent of task weighted moderate-to-vigorous physical activity.

[6]PA Cut point 4= 3.0 Metabolic equivalent of task unweighted moderate-to-vigorous physical activity.

[7]PA Cut point 5= 4.6 Metabolic equivalent of task unweighted light physical activity.

[8]PA Cut point 6= 4.6 Metabolic equivalent of task weighted moderate-to-vigorous physical activity, before and after school.

Table 4. Multivariate Linear Regressions for Selected Dependent Variables Log BMI, Percent Body Fat

Variable	[1]Log BMI		Percent Body Fat	
	Estimate (SE)	p-value	Estimate (SE)	p-value
Intercept	3.05 (0.04)	<.0001	29.86 (1.5)	<.0001
Walk Score	-0.00015 (0.0004)	0.71	-0.007 (0.02)	0.80
Race/ethnicity				
Hispanic	0.07 (0.03)	0.01	2.76 (1.18)	0.02
Black	0.03 (0.02)	0.22	-2.47 (1.00)	0.01
Other	0.01 (0.02)	0.55	0.49 (1.00)	0.62
White	REF		REF	
Mother's Education				
High school or less	0.07 (0.02)	0.004	2.60 (1.04)	0.01
College/some college	0.02 (.02)	0.31	0.75 (0.92)	0.42
Professional degree/beyond	REF		REF	
[2]FARL				
[2]FARL Unknown	0.004 (0.04)	0.92	-0.15 (1.83)	0.94
[2]FARL No	-0.01 (0.02)	0.64	0.13 (0.92)	0.89
[2]FARL Yes	REF		REF	
Treatment				
Control	-0.01 (.03)	0.71	-0.11 (0.92)	0.91
Intervention	REF		REF	

[1]Log BMI= Body mass index (weight kg/ height m^2).
[2]FARL=Free and reduced lunch recipient status.

The results obtained from multivariate linear regression for physical activity are reported in Table 5. No association was found between walk score and log physical activity levels, however results for the log average daily minutes of 4.6 MET weighted

MVPA before and after school show that there is a trend for a significant association with a beta coefficient of 0.002 and p-value of 0.09.

Table 5. Multivariate Linear Regressions for Selected Dependent Variables [1]Log MET Weighted MVPA

Variable	[1] Log 4.6 MET Weighted minutes of MVPA		[2] Log 4.6 MET Weighted minutes of MVPA, before and after school	
	Estimate (SE)	p-value	Estimate (SE)	p-value
Intercept	4.67 (0.11)	<0.0001	3.84 (0.12)	<0.0001
Walk Score	0.001 (0.001)	0.31	0.002 (0.001)	0.09
Race/ethnicity				
Hispanic	-0.08 (0.07)	0.29	-0.11 (0.10)	0.25
Black	0.02 (0.06)	0.77	0.040 (0.08)	0.62
Other	-0.01 (0.06)	0.94	0.11 (0.08)	0.16
White	REF		REF	--
Mother's Education				
High school or less	0.02 (0.06)	0.73	0.06 (0.08)	0.47
College/some college	0.06 (0.06)	0.28	0.10 (0.08)	0.17
Professional degree/beyond	REF		REF	--
[3]FARL				
[3]FARL Unknown	-0.05 (0.11)	0.67	0.01 (0.15)	0.9639
[3]FARL No	-0.05 (0.06)	0.37	-0.08 (0.08)	0.3177
[3]FARL Yes	REF		REF	--
Treatment				
Control	0.01 (0.11)	0.90	0.05 (0.06)	0.41
Intervention	REF		REF	--

[1] Log 4.6 metabolic equivalent of task weighted moderate-to-vigorous physical activity.
[2] Log 4.6 metabolic equivalent of task weighted moderate-to-vigorous physical activity, before and after school.

The results obtained from mixed logistic regression analysis for body composition are reported in Table 6 and indicated there is no association between walk score and odds of being at-risk-for-overweight/overweight (OR: 1.00, 95% CI: 0.99-1.00). This can be interpreted as after controlling for the covariates, each one unit increase in the walk score is associated with a 1.00 times increased odds of being at-risk-for-overweight/overweight.

Table 6. Odds Ratio and 95% Confidence Interval of Normal [1]BMI Vs. [2]At-risk-for-Overweight/Overweight

Effect	Odds Ratio (OR)	95% Confidence Interval	Estimate	p-value
Intercept	3.37	1.56-7.31	1.22	0.04
Walk Score	1.00	0.99-1.00	-0.004	0.35
Hispanic	0.55	0.32-0.97	-0.59	0.04
Black	0.91	0.56-1.50	-0.09	0.71
Other	1.28	0.76-2.18	0.25	0.35
White	REF	--	--	--
Mother's Education				
High school or less	0.52	0.30-0.89	-0.66	0.02
College/Some college	0.65	0.40-1.07	-0.43	0.09
Professional degree or beyond	REF	--	--	--
[3]FARL				
[3]FARL Unknown	1.12	0.46-2.72	0.11	0.81
[3]FARL No	1.47	0.94-2.28	0.38	0.09
[3]FARL Yes	REF	--	--	--
Control	0.92	0.59-1.43	-0.09	0.70
Intervention	REF	--	--	--

[1]BMI= Body mass index (weight kg/ height m^2).
[2]At-risk-for-overweight/overweight = Body mass index ≥85th percentile BMI.
[3]FARL=Free and reduced lunch recipient status.

The results obtained from mixed logistic regression analysis for physical activity outcomes are reported in Table 7 and 8 indicate that there is no association between walk score and meeting physical activity recommendations using either the 4.6 MET cut point (OR: 0.99, 95% CI:0.97-1.01) or the 3.0 MET cut point (OR: 1.01, 95% CI: 1.00-1.02). Controlling for the covariates, with each one unit increase in the walk score being associated with 0.99 increased odds and 1.01 increased odds of meeting physical activity recommendation for the 4.6 MET cut point and 3.0 MET cut point respectively.

Table 7. Odds Ratio and 95% Confidence Interval of Meeting Physical Activity Guidelines Vs. Not Meeting Physical Activity Guidelines ([1]4.6 MET Weighted MVPA)

Effect	Odds Ratio	95% Confidence Interval	Estimate	p-value
Intercept	0.04	0.01-0.26	-3.34	0.03
Walk Score	0.99	0.97-1.01	-0.008	0.50
Race/Ethnicity				
Hispanic	0.46	0.10-2.19	-0.78	0.33
Black	0.13	0.02-1.08	-2.01	0.06
Other	0.87	0.30-2.56	-0.14	0.80
White	REF	--	--	--
Mother's Education				
High school or less	2.68	0.63-11.32	0.99	0.18
College/Some college	2.74	0.74-10.11	1.01	0.13
Professional degree or beyond	REF	--	--	--
[2]FARL				
[2]FARL Unknown	1.01	0.10-9.98	0.01	0.99
[2]FARL No	1.20	0.35-4.03	0.18	0.77
[2]FARL Yes	REF	--	--	--

Treatment				
Control	0.66	0.24-1.82	-0.41	0.4
Intervention	REF	--	--	--

[1]4.6 Metabolic equivalent of task weighted moderate-to-vigorous physical activity.
[2]FARL=Free and reduced lunch recipient status.

Table 8. Odds Ratio and 95% Confidence Interval of Meeting Physical Activity Guidelines Vs. Not Meeting Physical Activity Guidelines ([1]3.0 MET Weighted MVPA)

Effect	Odds Ratio	95% Confidence Interval	Estimate	p-value
Intercept	2.50	0.85-7.29	0.95	0.17
Walk Score	1.01	1.00-1.02	0.007	0.16
Race/Ethnicity				
Hispanic	1.20	0.68-2.10	0.18	0.53
Black	1.10	0.68-1.78	0.10	0.69
Other	1.00	--	--	--
White	1.20	0.68-2.10	0.18	0.53
Mother's Education				
High school or less	0.56	0.22-1.43	-0.58	0.23
College/Some college	0.68	0.41-1.14	-0.38	0.14
Professional degree or beyond	REF	--	--	--
[2]FARL				
[2]FARL Unknown	0.80	0.20-3.14	-0.22	0.75
[2]FARL No	0.57	0.29-1.12	-0.56	0.10
[2]FARL Yes	REF		0	
Treatment				
Control	1.03	0.34-3.09	0.03	0.96
Intervention	REF	--	--	--

[1]3.0 Metabolic equivalent of task weighted moderate-to-vigorous physical activity.
[2]FARL=Free and reduced lunch recipient status.

In addition to the above stated results, we found no significant association between walk score and average daily minutes of 4.6 MET unweighted MVPA, average daily minutes of 3.0 MET unweighted MVPA, or average daily minutes 4.6 MET light physical activity (data not shown).

For the 186 spring 2003 participants with GIS measures available, the mean walk score was 37.11. Pearson correlation coefficients revealed a positive correlation of $r=0.63$ $p<0.0001$ between GIS derived index of neighborhood walkability and walkscore.com neighborhood walk score. Chi-square test of categorical variables and t-test for continuous variable revealed no significant differences of main demographic characteristics, and dependent variables except for a slightly lower mean neighborhood walk score in the spring 2003 sample (score of 37 compared with 42 in spring 2006 sample).

Chapter 4: Discussion

This study used an objective measure of the built environment (walkscore.com) to investigate the relationship between neighborhood walk score and physical activity levels as well as the body composition of adolescent girls. This analysis was unable to find and association with neighborhood walk score, as measured by walkscore.com and physical activity levels or body composition of adolescent girls. Despite this, we did find that when looking at before and after school activity only, the relationship between neighborhood walk score and physical activity was a trend toward significance. Additionally, we were unable to find an association between neighborhood walk score and obesity/overweight status or with meeting physical activity recommendations of 60 minutes or more of MVPA per day. Last, neighborhood walk score is positively correlated with a GIS derived index of walkability, providing validity to the walkscore.com measure.

To our knowledge, this is the first study to examine the relationship between neighborhood walk score and physical activity levels among adolescents. In contrast to Van Dyck et al.'s results in Belgian adolescents, we were unable to find an association between walk score and physical activity. Although neighborhood walkability is associated with increased physical activity level in US adults (Sallis et al., 2009) the lack of association found in this analysis may be due to factors such as neighborhood safety and parental permissiveness that may be important determinants in adolescent physical activity levels within the neighborhood environment and were unable to be accounted for in this study. Others have found that neighborhood crime is a barrier associated with participating in physical activity (Moore et al., 2010). Neighborhood crime levels of this sample were not assessed so it is unknown if crime impacted physical activity levels independent of neighborhood walk score. In particular parents of adolescent girls may not permit their child to make walking and cycling trips due to safety concerns. A recent Australian study by Carver et al. (2010) found that parents of adolescent girls reported more parental restriction related to outdoor physical activity in their neighborhood compared with parents of adolescent boys. Additionally, Carver et al. (2010) found that adolescent girls had statistically significant lower levels of physical activity after school compared to boys.

When activity during school was excluded we were able to see a trend towards significance. This could possibly be explained by active commuting to school, as neighborhoods with higher walk scores may be more likely to be in walking distance to the school. Consistent with Saksvig et al., (2008), adolescent girls that self-report walking for transportation before and after school have significantly higher levels of MVPA compared to girls that report never engaging in walking for transportation.

Although previous studies have found that a more walkable neighborhood is associated with decreased levels of overweight/obesity status in adults (Sallis et al., 2009), the present study was unable to find an association for a sample of adolescent girls. The type of destinations that girls may be frequenting could possibly explain this lack of association. Potentially, energy expenditure during physical activity within the neighborhood is offset by high caloric intake of snacks and beverages consumed at convenient neighborhood destinations. This would mean that regardless of the amount of physical activity girls are engaging in to get to the destination, the destinations that they visit encourage unhealthy eating behaviors. Destinations such as neighborhood convenience stores are often home to an abundance of energy dense snacks and sugar-sweetened beverages that are high in calories. British researchers Skidmore et al., (2009) found that in a sample of children, living in closer proximity to convenience stores, was associated with a greater consumption of: crisps, chips, sweets, chocolate and white bread, compared to children living in further proximity to convenience stores. They also found that a high density of grocery stores in the neighborhood was associated with higher levels of fruit and vegetable consumption (Skidmore et al., 2009). It may not necessarily be that neighborhoods have a variety of destinations conducive to participating in active travel, but that these destinations themselves may need to have qualities that positively influence individual's health. Previous studies have also shown that access to unhealthy foods in the neighborhood environment is associated with higher BMI in adolescents (Rose et al., 2009). Future studies that investigate neighborhood walkability and its influence on body composition should also assess the quality of the destinations within walking distance as well as dietary intake upon reaching neighborhood destinations. The neighborhood walkability measure in the present study was unable to examine the types of destinations outside of an aggregate score. In this sense, GIS may be a more useful measurement tool as it can populate specific types of establishments near an individual's home such as fast food outlets and convenience stores.

Despite these findings, neighborhood walkability as measured by the use of the website walkscore.com was positively correlated with a GIS derived index. Walkscore.com's neighborhood walkability is based on the proximity of amenities to a particular address of interest which is a similar to a measure of land mix use that is represented in the GIS index. GIS-derived land mix use measures five types of land use: residential, retail, entertainment, office and institutional, which are all also included as types of amenities in the walkscore.com measure.

It is interesting to note that even without measures of street connectivity and neighborhood density, neighborhood walkability measures from GIS and walkscore.com are correlated. This suggests that there is justification for using walkscore.com to measure an individual's neighborhood walkability score in place of a GIS derived index. Future studies that focus on understanding influences of the built environment as they affect individual physical activity behaviors may benefit from the use of walkscore.com to objectively measure neighborhood walkability. Additionally, walkscore.com is publicly available for no cost and can easily be utilized by researchers of all levels of technical experience and therefore is a cheap alternative to GIS for use in future research.

The findings of this analysis are surprising because evidence from Kuo et al. (2009) show that the most common location for adolescent girls physical activity was at the home or in the neighborhood. Kuo et al. (2009) also found that girls commonly reported engaging in activities such as walking for transportation or exercise and running/jogging. Similarly, Dowda et al. (2004) report that the most common activities that adolescent girls participated in where walking, basketball, jogging/running, bicycling and dance. This information would lead one to believe that a significant association between neighborhood walk score and physical activity levels would have been supported; however the present study was unable to find an association. This suggests that if a true association does exist between neighborhood walk score and physical activity levels it may not be apparent by the use of accelerometers as the measure of physical activity because accelerometers are known to poorly detect activities such as bicycling (Treuth et al., 2004), a traditional neighborhood based activity that adolescent girls participate in. Future studies looking at neighborhood physical activity should consider including a better objective measure of physical activities such as biking that may not be accurately accounted for from the use of accelerometer.

Strengths and Limitations

Strengths of this study include this is one of the first studies to investigate an objective measure of neighborhood walkability in a sample of adolescent girls. Many studies have reported on objective measures of the built environment influencing behavior in adults but few have done so in adolescents. This study also used objective measures of both physical activity levels and neighborhood walkability and collected body composition measurements by trained data collectors. The neighborhood walkability of the sample had considerable variation and the sample was a racially diverse group of girls.

This study had several limitations. First, due to the cross-sectional design of this data analysis, cause and effect relationships between neighborhood walk score and physical activity levels and body composition cannot be assessed. Since only 3% of the sample was categorized as meeting physical activity recommendations when using the 4.6 MVPA cut point, results from logistic regression analysis should be interpreted with caution. In addition, the use of walkscore.com has potential limitations because it does not archive the neighborhood walk score, therefore we are unable to assess the neighborhood walk score in the year 2006 when the TAAG physical activity and body composition data were originally collected. The walk score as provided by walkscore.com reflects the neighborhood walkability based on the amenities available in

2009. Despite this, neighborhood amenities do not change significantly over this small period of time. Additionally, walkscore.com does not account for other variables that may influence physical activity and walking in one's neighborhood such as sidewalks, crime and general aesthetics which are factors related to the built environment that are thought to be associated with obesity status in children (Singh, Siahpush & Kogan, 2010). Furthermore, the correlation of the GIS derived walkability index and the walkscore.com neighborhood walkability score was assessed for a different sample of girls then the regression analysis. This means the assumption of validity of neighborhood walkability as assessed by walkscore.com was applied to a sample where the correlation between GIS and walkscore.com could not be confirmed. Sample demographic characteristics were not significantly different aside from mean neighborhood walk score. This could possibly be explained by a smaller sample size and despite this difference, it is expected that a correlation between the two measures of neighborhood walkability would still be present.

Conclusions

In this analysis, we were unable to find an association between neighborhood walk score and physical activity levels or body composition of adolescent girls from the TAAG Maryland field site. Importantly, this study was able to confirm a significant positive correlation between neighborhood walkability as measured by walkscore.com and a GIS derived index. Future studies of neighborhood walkability as a determinant of adolescent girl's physical activity levels and body composition should also consider specific destinations frequented in the neighborhood when the neighborhood is the place where physical activity is being promoted. Future studies may also benefit from combining nutritional intake at active travel destinations to further describe the relationship of the built environment influences on body composition. Last, future studies should be conducted to replicate the correlation between walkscore.com and a GIS derived walkability index.

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