7 Examining Urban Environment Correlates of Childhood Physical Activity and Walkability Perception with GIS and Remote Sensing

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7.1 Introduction

Emerging research suggests that the built environment has potential to influence physical activity which, in turn, can have a protective effect against obesity and a positive impact on public health (Berrigan and Troiano, 2002; Atkinson et al., 2005). As a result, research on the association between the built environment and health is receiving increased attention in a variety of disciplines. Most research on the associations between the built environment and physical activity to date has focused on adults, but the potential links in children are largely unexplored. The present study examines how GIS and remote sensing can be used to enhance understanding of the relationships between physical activity and the built environment for a cohort of children from low-income urban neighborhoods in Indianapolis, Indiana.

Obesity has increased substantially in the United States over the last 30 years (Tremblay and Willms, 2000; Strauss and Pollack, 2001). The percentage of overweight children age 6 – 11 in the U.S. has grown from 4% in 1965 to 13% in 1999. The rate of overweight adolescents age 12 – 19 rose from 5% in 1970 to 14% in 1999 (Ogden et al., 2002). Obesity is costly in terms of decreased physical and psychological health (Hill and Peters, 1998; Cummins and Jackson, 2001; Liu and Hannon, 2005) -- in 1998 aggregate adult medical expenditures attributable to overweight and obesity is estimated to be $51.5 billion using Medical Expenditure Panel Survey data and $78.5 billion using 1998 National Health Accounts data. Research further suggests that increased obesity may eventually lower life expectancy in the U.S. (Olshansky et al., 2005).

Growing concerns over the obesity epidemic have prompted research into the potential effects of the built environment on physical activity and human behavior (e.g., King et al., 2000; Brownson et al., 2001; Pikora et al., 2003; Burdette and Whitaker, 2004; Hoehner et al., 2005). Promoting physical activity through environmental interventions adopts a population-based approach to behavior modification with the idea that altering the environment encountered by many people will have a greater cumulative impact on public health than individual intervention. Increasing physical activity through environmental modification that promotes routine physical activities, such as walking and cycling, may also be more effective because sedentary people are more likely to adopt moderate vs. vigorous forms of exercise and still accrue significant health benefits (Epstein et al., 1997; Frank and Engelke, 2001).

Using methods drawn mostly from transportation studies, researchers have correlated features of the built environment with both self-reported (diaries) and objective data on people's physical activity (Frank et al., 2005). Certain types of urban patterns, such as sprawl, correlate negatively with physical activity (Ewing et al. 2003). At the neighborhood level, research has identified a correlation between physical activity and street pattern, land use, and pedestrian infrastructure (Cervero and Duncan, 2003; Saelens et al., 2003[a]). An increased presence of supermarkets has been associated with increased fruit and vegetable intake in both Black and White adults (Morland et al., 2002). Studies focusing on the built environment's roles as a determinant of childhood overweight remain inconclusive.

Geospatial technologies (including GIS, GPS, and remote sensing) are increasingly employed to facilitate the collection of objective environmental measurements in support of physical activity research. These data can be both spatially and categorically comprehensive, providing information that may supplement or replace more costly field data collection. In addition, geospatial data may provide more objective observations than those obtained through the use of trained observers or self-reported by subjects. In the current study, variations in children's physical activity levels and perceptions of neighborhood walking environments were examined in relation to GIS and remote sensing measures of the built environment. Environmental variables were summarized at multiple radii around children's residences to assess how distance influences the associations between environment, physical-activity, and walkability perception.

7.2 Data and Methods

Data on 463 children's perceptions of neighborhood walkability, physical activity levels, family incomes, and body mass indices were obtained from the 2004 Summer Health Assessment Program Education (SHAPE) conducted by the Marion County Health and Hospital Corporation (Primary Investigator: Wanda S. Roddy, Marion County Department of Health). SHAPE is an annual program designed to medically evaluate and improve health care access for low-income children and their families in Indianapolis, Indiana. The program includes physical examinations conducted by physicians or nurse practitioners wherein children's height, weight, and body mass index (BMI) are determined. Children were classified by age- and gender-adjusted BMI percentiles, with a BMI greater than the 85^{th} percentile being considered 'at risk for overweight' and greater than the 95^{th} percentile being 'overweight'. The total number of children included in the 2004 program was 559.

As part of the SHAPE evaluation, children were asked to complete surveys on physical activity levels and perceptions of neighborhood walkability. Children's parents were asked to describe the child's medical history and family demographics. Demographic information collected as part of the survey included age, race, gender, annual family income, and overweight status. Five questions taken from the National Safety Council (2002) related to neighborhood walkability were included as part of the survey (Table 1). Subjects in SHAPE tend to be from poor minority families when compared to census indicators for the city as a whole. While the 2000

Census indicated that 14.7% of Indianapolis families have an annual income less than $15,000, 82.1% of SHAPE families fall below that threshold. The SHAPE survey included seven options for race. In the current study, race responses were condensed into 5 categories including one for no response. Similarly, income data were summarized in five categories including one for no response. Responses to the question, "How many days each week do you exercise, dance, or play sports?" are summarized in Figure 1.

Table 1. Subject characteristics and responses to SHAPE survey items.

Age	Younger than 5y		26	(6%)
	5 – 8y		192	(42%)
	9-12y	190	(41%)	
	13y and older	53	(11%)	
Sex	Female		225	(49%)
Race/ethnicity	Black	330	(71%)	
	Hispanic		42	(9%)
	White		45	(10%)
	Other			
Income	No Response	20	(4%)	
	Less than $9,000		205	(44%)
	$9,001 - $12,000		138	(30%)
	$12,001 - $15,000		35	(8%)
	Greater than $15,001	65	(16%)	
Weight Status	Normal Weight	216	(47%)	
	At Risk of Overweight	130	(28%)	
	Overweight		95	(21%)

Do you have room to walk?					
Yes	429 (93%)	No	28 (6%)	Unsure	4 (1%)
Is it easy to cross the street?					
Yes	388 (84%)	No	66 (14%)	Unsure	6 (1%)
Did drivers behave well?					
Yes	277 (60%)	No	123 (27%)	Unsure	57 (12%)
Were you able to follow safety rules?					
Yes	428 (92%)	No	14 (3%)	Unsure	17 (4%)
Was your walk pleasant?					
Yes	401 (87%)	No	21 (5%)	Unsure	28 (6%)

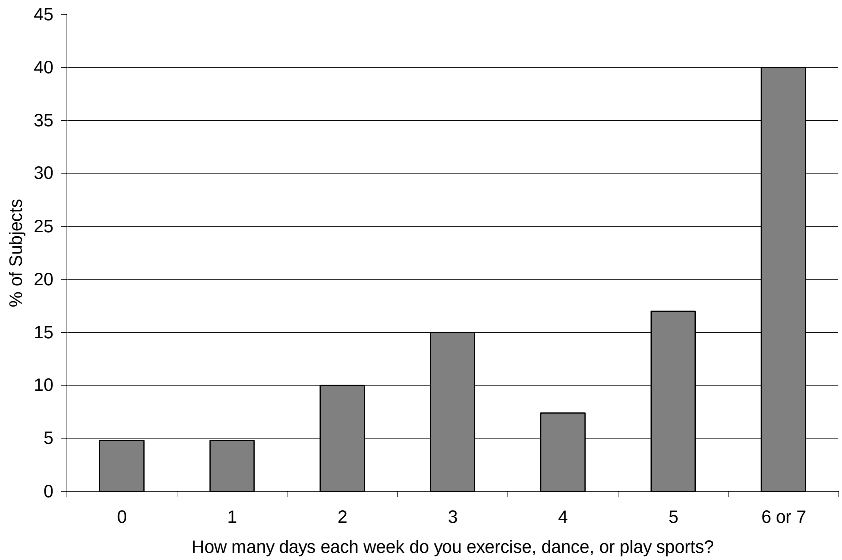

Fig. 1. SHAPE Subject Responses to the Question "How many days each week do you exercise, dance, or play sports?".

Address data collected as part of the survey were used to develop a GIS point layer representing the location of children's primary residences. Geocoding was accomplished using street center line and address range data provided by the Indianapolis Mapping and Geographic Information Service (IMAGIS) and standard GIS address matching routines. There were 559 individual children living at 390 unique addresses indicating that some locations included more than one child. Three hundred seventy of the 390 address were successfully geocoded (94.9% match rate) yielding point locations for 535 children (95.7%). Points located within a distance of 1km from the border of the Indianapolis city limits (n = 22) were excluded because of the lack of some geospatial data outside of the city boundary, leaving 513 (91.8%) child residential locations for analysis (Figure 2). Circular buffers were generated around the point locations representing children's residences at distances of 200m, 400m, 600m, 800m, and 1km in order to evaluate the influence of environmental characteristics at multiple radii. Environmental characteristics evaluated as independent variables included: crime density, street intersection density, residential population density, neighborhood median family income, speed limit and traffic counts, sidewalk density, building offset, land use diversity, and the Normalized Difference Vegetation Index (NDVI).

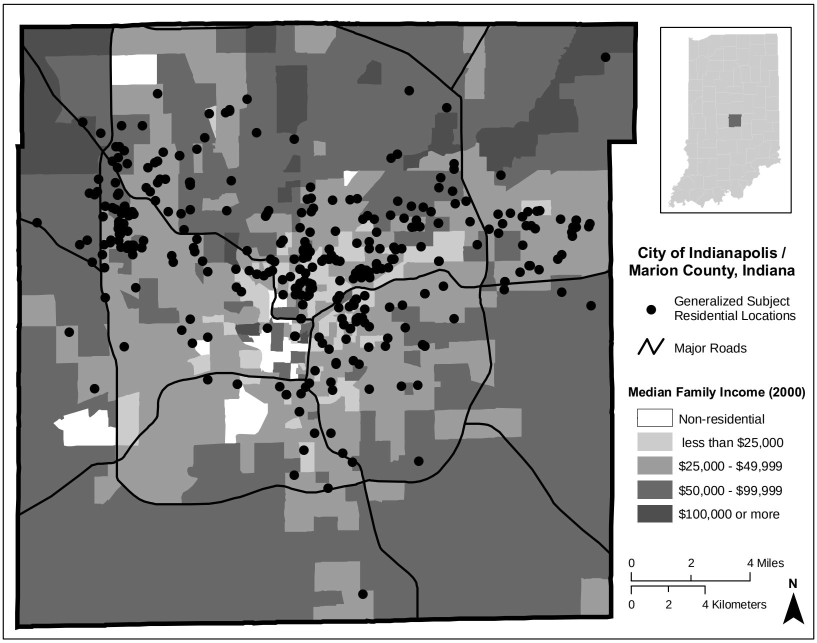

Fig. 2. Generalized SHAPE subject residential locations and median family income (2000) in Indianapolis / Marion County

Data on neighborhood median family income were obtained from the 2000 U.S. Census for all block groups in Marion County, Indiana. Median income data were converted to a 30m resolution raster and the mean value within each child's corresponding buffers was calculated. One limitation of this method is that the final calculation for a given buffer distance provides a mean of median family income and thus assumes uniform distribution of income across the region.

Building footprints and right-of-way were combined to determine average building offset. Indianapolis's public right-of-way GIS layer represents areas reserved for public use such as roads, sidewalks and bike lanes. The building footprint layer includes almost 500,000 polygons representing structures in Marion County. Buildings less than 600 square feet were excluded from the analysis to prevent small buildings, such as sheds, from influencing the final results. Building offset was calculated by measuring the shortest distance from the edge of each building polygon to the right-of-way. The measurement was then applied to the points representing building centroids and the average of building offsets for all building centroids falling within a given buffer was calculated.

Intersection density has been used as a proxy for street connectivity, with more intersections indicating better connectivity (Frank et al., 2005). Street intersection density was calculated in the current study from a street centerline layer by determining the number of street network nodes within a given distance of children's residences. Nodes representing dead-end streets or cul-de-sacs were excluded. The number of intersections per unit area was summarized at each buffer distance around children's residences.

Traffic counts and speed limits of street segments falling within the residential buffers were averaged at each buffer distance. Traffic counts were available for arterial roads only, creating situations where some smaller buffers do not intersect with any arterial street segments generating a null value. Records that contain null values were excluded in subsequent analysis. The percentage of public streets serviced by sidewalks was estimated using Indianapolis's sidewalk and street centerline GIS layers. Street centerlines were divided into 30m sections and any section within 15m of a sidewalk was attributed as being serviced by a sidewalk. The total length of roads serviced by sidewalks was divided by the total length of all roads within a given buffer distance, yielding percent roads serviced by sidewalks around a child's residence.

Geocoded crime data for Marion County were obtained from the Indianapolis Police Department (IPD). The available data include all incident reports, regardless of whether or not a conviction was obtained. Incident reports for the 1998 calendar year were used in the current study as they were the most recent data available with complete coverage of the city. Incident report locations were aggregated by census block groups and normalized by the area of each block group yielding a value of annual crime density. This crime density variable was then rasterized to facilitate calculation of average crime density within each buffer distance around children's homes.

Current planning techniques, such as Smart Growth, are intended to reduce reliance on automobiles, increase walking for transportation, and reduce pollution from vehicle emissions (Saelens et al., 2003[b]). Mixed use neighborhoods that include amenities, such as sidewalks and crosswalks, enhance walkability by placing people within practical walking distance of destinations (e.g. retail stores, post offices, and leisure facilities). Indianapolis zoning data were used to develop a land use dissimilarity index in the current study to capture land use heterogeneity around children's residences. These data delineate 70 unique types of zoning in the study area including 9 levels of residential density, commercial and industrial uses, and special use zones including schools, parks, cemeteries and churches. Land use data surrounding a hypothetical residential location are depicted in Figure 3 along with selected features of the built environment.

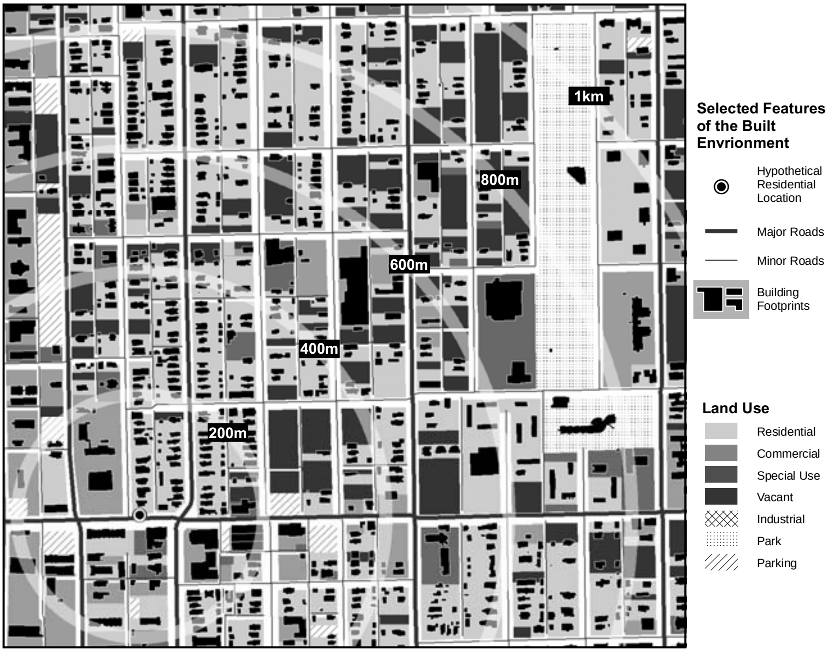

Fig. 3. Land Use and selected features of the built environment surrounding a hypothetical residential location.

The present study employed a version of the land use dissimilarity index developed by Frank et al. (2005) modified to adjust for the focus on children rather than adults. Frank's system divides land use into three categories (residential, commercial, and office) with the premise that commercial and office districts provide destinations for those living in residential areas. Recreational zones (including parks, playgrounds, and school yards) were substituted in place of office space in the current study, assuming these land use types would be more likely destinations for children than offices.

Data from the 2000 U.S. Census were used to develop residential population density estimates within children's residential buffers following the protocol of Forsyth et al. (2005). Average population density was calculated by weighting the census block group population density by the area of the block group falling within a child's residential buffer. The estimated population inside the buffer was divided by the total area of residential zoning, yielding a density measure that accounts for variation in land use.

A walkability index was calculated using the equation of Frank et al. (2005) that combines population density, intersection density and land use dissimilarity:
Walkability index = (6 x Z-score of land-use mix)
+ (z-score of net residential density)
+ (z-score of intersection density)
The results will vary based on the z-score inputs, which ranged from -15.67 to 18.47 in the current study.

The normalized differential vegetation index (NDVI) is a remotely sensed measure of the presence and condition of vegetation (Lillesand et al., 2005). NDVI values range from -1 (bare ground) to +1 (dense, healthy vegetation). NDVI data were calculated from Landsat Enhanced Thematic Mapper Plus (ETM+) imagery acquired May 8, 2001 using the equation (Near Infrared Band - Red Band) / (Near Infrared Band + Red Band) (Tucker, 1979) (Figure 4). Average NDVI values were calculated at each of the five buffer distances around children's residences.

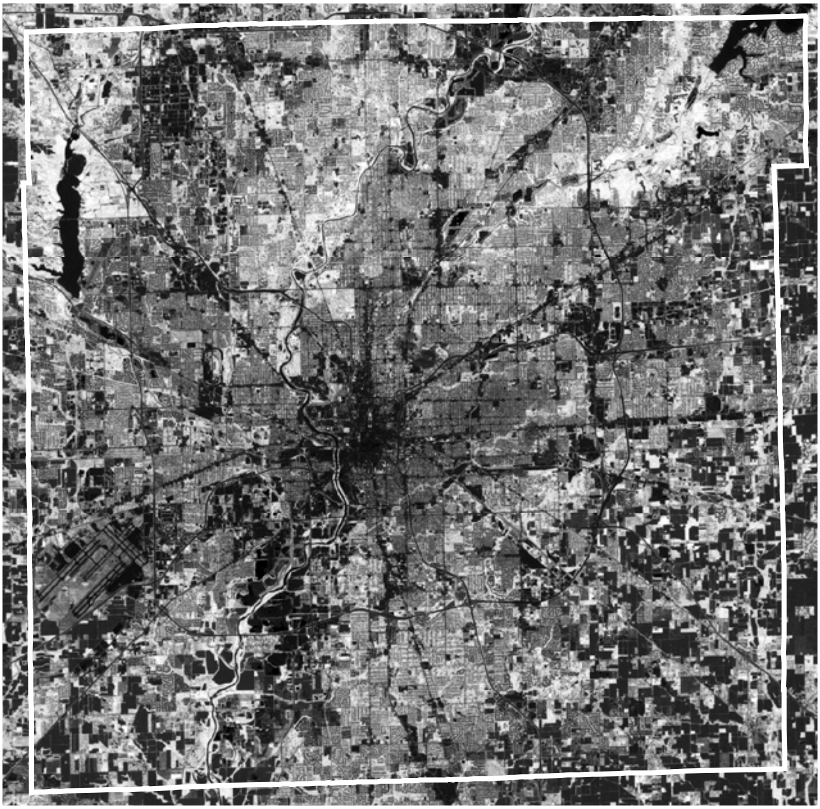

Fig. 4. Enhanced Thematic Mapper Plus (ETM+) Normalized Difference Vegetation Index (NDVI) Image of Indianapolis / Marion County, Indiana (May 8, 2001). Brighter tones indicate higher NDVI values.

Methods

Analysis was conducted in three phases designed to examine: 1) the relationship between children's perceptions of neighborhood walkability and environmental variables, 2) the relationship between children's self-reported physical activity and the built environment, and 3) the performance of regression models for predicting physical activity level of children using their perceptions of walkability, built environment variables surrounding their residences, and individual-level sociodemographics.

To examine relationship between children's perceptions of neighborhood walkability and environmental variables, T-tests were conducted to determine whether environmental variables had significantly different mean values between the groups of children responding in the affirmative or negative to the National Safety Council (NSC, 2002) neighborhood walkability survey questions. The question "Do you have room to walk?" was compared to building offset and percentage of roads serviced by sidewalks. Responses to the question "Was your walk pleasant?" were compared to NDVI and the land use dissimilarity index. Street intersection density was compared to two questions: "Were you able to follow safety rules?" and "Was it easy to cross the road?" The question related to drivers' behavior was analyzed against speed limits and traffic counts.

To examine relationship between the built environment and children's self-reported physical activity levels, T-tests compared mean values of each independent variable at multiple radii for children in high versus low physical activity categories. High physical activity was assigned to children reporting six or more days per week with physical activity. Our choice of this dichotomous outcome was informed by the U.S. Department of Health and Human Services recommendation that children and adolescents engage in 60 minutes of moderate exercise most days, preferably daily (Pate et al., 1995). We chose a cut-point of six days per week because the variation of responses was skewed and this threshold represented a natural break in the distribution (Figure 1).

Both logistic and linear regression models were developed to predict physical activity levels of children using their perceptions of walkability, built environment variables, and individual-level sociodemographics. Built environmental variables were included in the multivariate models if the associated T-test in phase 1 of the analysis was significant at the 0.05 level. Black was used as the reference category for race during regression analysis. Family income level of $9,000 - $12,000 was used as the reference category for income.

7.3 Results

Two environmental variables, NDVI and speed limit, were found to have significant relationships to children's neighborhood walking perceptions. NDVI was positively associated with the question "Was your walk pleasant?" at three buffer distances: 600m, 800m and 1km. Children who reported experiencing a pleasant walk in their neighborhood had higher mean NDVI values compared to children who did not rate their neighborhood as providing a pleasant place for walking (mean NDVI at 600m buffer = 0.095, SD ± 0.087 for children with pleasant walks versus 0.054 ± 0.079 for those without, p-value 0.03). The relationship became stronger as the buffer distance increased (mean NDVI for 1km buffer = 0.093 ± 0.085 for children with pleasant walks versus 0.045 ± 0.08 for those without, p value 0.02). Speed limit had significant relationships with perceptions of driver behavior at all buffer distances. In response to the question "Did drivers behave well?" children who affirmed drivers in their neighborhoods as "well-behaved" had significantly lower mean speed limit values within their residential buffers (e.g. mean speed limit at 1km buffers 29.4 ± 2.4 mph for those children reporting well-behaved drivers versus 30.2 ± 1.9 mph, p-value 0.001).

Children living in poorer neighborhoods, with more traffic, higher speed limits, more intersections, higher crime rates, and lower NDVI tended to report higher physical activity levels. Mean intersection density (156.3 ± 71.7 intersections in high activity children versus 144.0 ± 55.4 intersections in low activity children, p-value 0.04) and average speed limit (29.9 ± 2.2mph in high activity children versus 29.4 ± 2.5 mph in low activity children, p-value 0.02) differed significantly for the physical activity subgroups only at the 1km buffer distance. Mean traffic counts differed significantly for the physical activity subgroups at 400m and 800m with the strongest relationship observed at 800m (916 ± 305 vehicles per day for high activity children at 800m versus 851 ± 326 vehicles per day for low activity children, p-value 0.03). Density of crimes showed a significant and positive relationship only at the 200m buffer distance (3164 ± 2543 annual crimes for high activity children versus 2711 ± 2287 annual crimes for low activity youth, p-value 0.04). NDVI and physical activity were negatively related at every buffer distance except 200m, with 1km showing the strongest relationship (mean NDVI at 1km buffer for high activity children 0.079 ± 0.09 versus 0.074 ± 0.01 for low activity youth, p-value 0.009). Neighborhood median family income had a negative relationship with physical activity at every buffer distance except 1km, with 200m showing the strongest relationship ($38,312 ± $14,943 for high activity children versus $42,225 ± $15,476 for low activity children, p-value 0.006).

These results led to the transfer of the following variables to the regression models in part three of the analysis: intersection density at 1km, average speed limit at 1km, traffic counts at 800m, crime density at 200m, NDVI at

1km and neighborhood median family income at 200m. The dependent variable for the linear regression model was the number of days per week children reported being physically active. The dependent variable in the logistic regression setting was a binary indication of high or low physical activity level as previously defined. Seven significant relationships emerged in the linear model and five in the logistic model. The significant relationships in the linear model were: Hispanics were less active; older children were less active; children overweight or at risk of being overweight were less active; children in the lowest family income (demographic variable) category were more active; children near roads with higher traffic counts were more active; children perceiving well-behaved drivers were more active; and children reporting pleasant walks were more active. The models estimated that children reporting presence of pleasant walks in their neighborhood would be expected to report an additional day per week of activity. Children who perceived drivers as well behaved in their neighborhoods would be expected to report an additional one half-day per week of activity than children reporting that neighborhood drivers were not well behaved. The logistic model resulted in significant relationships for age, overweight status, reported family income, traffic counts and pleasant walks, all in the same direction as the linear model. Complete regression model results are shown in Table 2.

Table 2. Regression model using demographic, neighborhood walkability, and geospatial environmental variables to predict self-reported physical activity levels (Significant at .05 in bold).

	Linear Regression $r^2 = .105$		Logistic Regression $r^2 = .197$		
	Outcome: Number of Days Active		Outcome: Physical Activity High or Low		
Variable	Standardized Beta	Sig.	Standardized Beta	Standard Error	Sig.
Age	-0.131	**0.016**	-0.102	0.042	**0.015**
Hispanic	-0.124	**0.020**	-0.836	0.513	0.103
White	-0.073	0.233	-0.559	0.414	0.177
Other Race	0.010	0.850	0.325	0.495	0.512
Female	-0.014	0.786	-0.201	0.238	0.398
BMI > 85^{th} percentile	-0.148	**0.004**	-0.711	0.241	**0.003**
Income under $9K	0.255	**0.000**	0.825	0.301	**0.006**
Income $12-$15K	0.045	0.423	-0.239	0.472	0.612
Income > $15K	-0.007	0.901	-0.425	0.366	0.246
Intersection Density 1km	-0.045	0.620	0.001	0.003	0.821
Speed Limit 1km	0.035	0.525	0.053	0.056	0.347
Traffic Count 800m	0.140	**0.014**	0.001	0.000	**0.008**
NDVI 1km	-0.092	0.233	-1.741	2.059	0.398
Median Family Income	-0.120	0.080	0.000	0.000	0.217
Crime 200m	-0.054	0.541	0.000	0.000	0.584
Room to Walk	0.010	0.860	0.695	0.577	0.228
Easy to Cross Road	0.023	0.687	0.487	0.413	0.238
Well Behaved Drivers	0.162	**0.007**	0.489	0.302	0.105
Follow Safety Rules	0.007	0.891	-0.453	0.808	0.575
Pleasant Walks	0.156	**0.004**	1.429	0.630	**0.023**

7.4 Discussion

This study explored the use of geospatial data to enhance analyses on the associations between physical activity levels in children and the built environment in which they live. Estimates of environmental variables quantified using GIS and remote sensing were compared to children's perceptions of their walking environments and reported levels of physical activity. Variables representing walking perceptions, demographics, and the environment were used in regression models predicting physical activity. Self reported variables representing perceptions of the built environment were significantly related to GIS variables meant to function as objective measures of the built environment. Different sizing of analytic buffers influenced associations between environmental variables and physical activity. We found that after controlling for individual demographic factors, individual weight status, and neighborhood socioeconomic status, the following factors related to the built environment were significant predictors of physical activity in children: presence of heavier traffic, perceiving drivers to be well-behaved, and perceiving walks to be pleasant.

The findings of significant associations between child self-perceptions of driver behavior and neighborhood infrastructure comprising pleasant walking paths are, to our knowledge, novel. These findings compliment studies that heretofore have included only adult subjects. The presence of heavy traffic has been associated with higher levels of physical activity in adults and adults who perceive enjoyable scenery along walking routes have been shown to be more likely to walk (Brownson et al., 2001). In contrast to the present study, the work by Brownson et al. obtained quantification of traffic levels and pleasing scenery from subjects' survey responses, while the current study employed both survey methods as well as direct observations recorded as GIS variables.

Of particular relevance to this study are urban design initiatives such as New Urbanism (Katz 1994) and the Ahwahnee Principles (Corbet and Valesquez 1994) for resource-sufficient communities. These initiatives call for the development of integrated communities containing mixed residential, commercial, and open recreational land uses in easy walking distance of one another and transit stops; the design of streets and paths that slow traffic and result in a fully connected system of intersecting routes to all destinations; and the design of neighborhoods to support diversity in age and socioeconomic status levels of residents, encouraging the presence of people in public space. Although this study cannot elucidate how heavier traffic, driver behavior, and pleasant walks promote youth physical activity, it can be argued that each of these phenomena could be related to the availability of destinations and pedestrian safety, both of which are logically supportive of walking.

Many of the environmental factors that were examined did not emerge as significant predictors of child physical activity, in contrast to several previously published studies. Norman et al. (2006), for example, found that girls in areas of lower intersection density were more likely to exhibit lower levels of physical activity. Independent environmental variables common to both Norman's and the present study include residential density, intersection density, land use mix, and a walkability index. Gordon-Larsen et al. (2000) found serious crime was associated with a lower likelihood of moderate to vigorous physical activity in adults. The current study indicated no relationship between crime and physical activity level in children, but made no distinction between serious and non-serious crime as in the Gordon-Larsen study. Further research is needed to assess how crime levels in neighborhoods may differentially influence persons of various ages. Consistent with the results of Hoehner et al. (2005), who found sidewalk density was not a significant predictor of walking for pleasure or transportation among adults, no significant relationship between physical activity and the presence of sidewalks was observed for children in the current study. The distinction between recreational and utilitarian walking may be especially relevant for the younger subjects in our study, as children may be more apt to engage in active play along streets in contrast to adult utilitarian purposes (e.g. walking to work or to retail areas).

Limitations of this study include the narrow demographic scope (predominance of racial minorities and families with lower incomes) of the subjects, survey questions that were not designed specifically to facilitate GIS analysis, and potentially unreliable survey answers due to the young age of the respondents. The selection of specific buffer sizes may not have resulted in the most informative variable – possibly analytic areas smaller or larger would have resulted in more explanatory variables. Another problem may have been with the process of summarizing data in the buffers – in using the mean values for the analytic buffers, we may have missed important specific information. It is possible that much of the physical activity reported occurred at a location away from the children's home, such as at school or church, to which the children took vehicular transportation.

The associations between age, gender, and differences in physical activity in our study are consistent with national surveillance of youth health behaviors (Troiano and Flegal 1998). Interpretation of the relationship between family income and physical activity must take into account that the study population was drawn mainly from children of poor families attending free or reduced-cost summer camp programs. One interpretation could be that the poorest of the poor are more physically active than those with a higher economic standing. A possible explanation for this finding is that children in the lowest socioeconomic class would have less access to sedentary forms of entertainment such as TV and video games. The association may substantially change if more representation of families with high income were included. The relationship between income and physical activity may be curvilinear as more affluent children may have better access to more expensive forms of physical activity that require costly equipment.

7.5 Conclusions

Our study adds to an accumulating body of literature suggesting that aspects of the built environment are determinants of child weight status, ostensibly influencing health behaviors such as physical activity. Geographic information systems and remote sensing have potential to complement other means of collecting exposure data for a wide range of environmental and public health analyses. The current study contributes to previous research in two ways: the focus on children as opposed to adults, and the use of GIS-based variables alongside related survey data to quantify the urban environment in terms of walkability. Examining urban environment correlates of childhood physical activity and walkability perception through GIS and remote sensing should inform future public policy aimed at the prevention and management of obesity in the United States.

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