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Youth Destinations Associated with Objective Measures of Physical Activity in Adolescents

Angie L. Cradock, ScD[1], **Steven J Melly, MS**[2], **Joseph G. Allen, DSc**[3], **Jeffrey S. Morris, PhD**[4], and **Steven L Gortmaker, PhD**[1]

[1]Department of Society, Human Development and Health, Harvard School of Public Health, Boston, MA

[2]Department of Environmental Health, Harvard School of Public Health, Boston, MA

[3]Environmental Health & Engineering, Inc., Needham, MA

[4]Department of Biostatistics, University of Texas MD Anderson Cancer Center, Houston, TX

Abstract

Background—Limited availability of desirable destinations within walkable distances and unsuitable weather may adversely affect physical activity among adolescents on weekends.

Methods—Students (n=152, 59% male, mean age 13.7 years) from 10 neighborhoods with schools in four communities wore TriTrac-R3D accelerometers recording physical movements on weekends. Minute-by-minute data were summed over 15-minute intervals providing estimates of proportion of time spent in moderate and vigorous physical activity (MVPA) and (log) mean physical activity levels on weekends (n=7506 intervals). Objective measures of neighborhood characteristics were calculated using geographic information systems including average daily traffic, housing density, open space, and density of employees/ km^2 in youth destinations. Linear mixed models were fit examining associations between neighborhood environmental variables and accelerometer measures of physical activity, controlling for time, day, age, BMI, sex of respondent, race/ethnicity, precipitation, and temperature deviation.

Results—On weekends, greater densities of employees in neighborhood destinations serving youth (β=3.96, p=0.050) was directly associated with MVPA, independent of student characteristics.

Conclusions—Young people attending schools in neighborhoods characterized by greater densities of employees in destinations for youth are more physically active on weekends. Compared with neighborhoods with lower densities, attending a school in neighborhoods with higher densities of employees in potential destinations for youth may contribute to participation in an additional 30 minutes of MVPA per day on weekends.

Corresponding Author and Reprint Requests: Angie L. Cradock, ScD, Department of Society, Human Development and Health, Harvard School of Public Health, Boston, MA, 02115. Phone: (617) 432-3874, Fax: (617) 432-3875, acradock@hsph.harvard.edu.

Author Contributions:
ALC, SJM, and SLG conceived of the idea for the manuscript, identified and collected data and assisted in the creation of measures, analysis of data, and preparation of manuscript
JGA assisted in the data collection, creation of measures, analysis, and the preparation of the manuscript
JSM devised statistical analysis strategy and contributed to the preparation of the manuscript

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Keywords

Physical Activity; Built Environment; Accelerometer; Neighborhood Characteristics

Introduction

Physical activity provides several health benefits for children and adolescents including increased fitness, reduced body fat, improved cardiovascular and metabolic disease risk and bone health, and decreased symptoms of depression and anxiety [1]. However, as few as 8 % of youth aged 12–15 years obtain moderate and vigorous physical activity sufficient to meet public health recommendations [2]. To address these dismal physical activity patterns, public health, planning and transportation researchers have focused on environmental features that may have the potential to influence transportation and recreation physical activity levels among children and adolescents [3–5].

Physical activity behaviors among adolescents are both context and domain specific [6]. While certain characteristics of the local neighborhood may be likely to influence a young person's decision to walk for transportation, other environmental factors may be related to physical activity associated with participation in sports or recreation. Factors such as neighborhood safety, traffic safety, access to household transportation options (e.g., physical access or proximity to destinations, vehicle access) [7] and physical attributes of neighborhoods, destinations (and their surroundings), and routes [8] are thought to influence a young persons choice and ability to walk for transport. Several studies support these hypothesized frameworks, suggesting that transportation-related walking among adolescents is influenced by physical environmental characteristics including (objective) measures of neighborhood residential [9–13] and intersection density [9], land use patterns [9–11] and traffic [10,14] and pedestrian safety features [15]. Recent reviews of the literature suggest access to local community parks, playgrounds, trails and physical activity programs are influential environmental correlates of recreational physical activity participation [3, 4].

Adolescents may be particularly sensitive to local neighborhood environments. National time use studies suggest that on weekends, compared with their younger counterparts, adolescents participate more frequently in organized and social activities, and in attending to personal business (including shopping) [16] and structured activities that are often pursued outside of the home [17]. As these types of leisure activities may include physical activity within different domains (e.g., transportation-related physical activity, sport or recreational physical activity) each may respond differently to local environmental characteristics. Copperman and Bhat [18] found that physically active travel (for utilitarian purposes) was directly associated with the number of restaurants and food stores and residential proximity to an urban area, while participating in active recreation including walking or biking around the neighborhood for leisure and other active pastimes was sensitive to variation in commercial and industrial land use, average block size and higher shares of multi-family residential units.

Studies examining the role of the local built environment and objectively measured physical activity among adolescents, while limited in number, suggest that overall physical activity levels are also sensitive to similar local characteristics. Jago and colleagues [19,20] found sidewalk characteristics were associated with measures of physical activity (i.e., decreased sedentary activity and increased light physical activity) [19], while availability of parks, crime and access to local gymnasium resources were inconsistent physical activity correlates [20]. Among 6th grade girls, residence near at least one commercial physical activity facility [21] or within one mile of parks (particularly those with amenities) [22] was associated with increased objectively measured, out-of-school time physical activity levels. Norman and colleagues [23] found that objectively measured environmental correlates of physical activity differed by gender for young people aged 11 to 15. For girls, the number of nearby recreation facilities and parks was directly associated with daily summary measures of physical activity while intersection density was inversely associated with physical activity. For boys, higher retail floor area (assumed to be indicative of a local neighborhood that is pedestrian-oriented) was positively associated with daily physical activity levels. Similarly, objective characteristics of the local road environments including the presences of speed humps and residence on a cul-de-sac have been associated with adolescent boys' (but not girls') physical activity levels in the evening hours [15].

Thus, pedestrian-friendly features and presence of desirable destinations within a walkable distance may affect physical activity levels among adolescents via their potential impact on transportation-related or recreational physical activity levels. This analysis examines evidence for the influence of objectively measured local environmental on overall physical activity occurring during weekend periods among middle school students.

Methods

The study environment comprises 10 neighborhoods with a middle school in four communities in the Boston Metropolitan area. According to the 2000 US Census, the average median household income of the zip code areas in which the schools were located ($48,485) was below the average for Massachusetts ($50,502) and ranged from $31,751 to $70,613. The proportion of households living in poverty in these areas ranged from 2% to 16% with a mean of 9%. The proportion of the population in these areas earning more than $200,000 ranged from 1–8%.

Data for this study were derived from a randomized controlled trial of a school-based interdisciplinary health education curriculum intervention among seventh and eighth grade students in 10 middle schools. The curriculum lessons focused on reducing television viewing time and consumption of high fat foods as well as increasing fruit and vegetable consumption and moderate and vigorous physical activity levels. The intervention was found to reduce television hours among both girls and boys. Additional findings suggested an increased fruit and vegetable consumption as well as a smaller increment in total energy intake among girls [24]. The study design matched schools on enrollment size and ethnic composition. A stratified random sample of 256 students participated in a sub-study that collected objectively monitored physical activity data in 1997. Monitoring protocols resulted in the collection of physical activity data for both weekends and weekdays in portion of study participants from each school. The research protocol was approved by the Human Subjects Committee at the Harvard School of Public Heath.

Student-Level Data

Student questionnaire data were also collected in 1997 to assess individual nutrition and physical activity-related behaviors and other student characteristics including sex, age, race and ethnicity. Body Mass Index (BMI) was calculated from measurements collected in 1997 by trained project staff [24]. Given the limited age range of participants, BMI was included as a study covariate. The data used in this analysis are from 152 study participants with both accelerometer data for weekend days and complete corresponding survey and BMI data for study covariates from 1997. Data from weekday monitoring periods have been analyzed separately.

Physical Activity Data

Data Collection and Reduction—The study protocol assigned students to wear the TriTrac-R3D accelerometer for either one or two four-day sessions conducted by school between February and May of 1997. Data were not collected simultaneously in neighborhoods. The students wore the accelerometers on their hip in a small pouch. The TriTrac-R3D collects measures of movement in three planes and provides a summary vector measure of movement, vector magnitude, for each minute. Validity of the TriTrac-R3D in measuring physical activity among children and adolescents has been assessed in comparison to heart-rate and uniaxial activity monitors and oxygen consumption for both structured and unstructured activities with correlations ranging from r=0.58 to 0.92 depending on the comparison [25]. Minute-by-minute TriTrac-R3D vector magnitude counts from students were reviewed. Periods with little or no movement recorded for 30 or more consecutive minutes (i.e., vector magnitude less than 10) were considered missing [26]. The vector magnitude data were averaged over consecutive 15-minute intervals for further analysis when no more than 5 of the minutes were missing, a strategy used in a prior analysis [27]. The strategy employing 15-minute averages allows for statistical control for time-of-day specific effects and day-to-day variability common in objective assessments of physical activity among youth [25, 28–30]. This adjustment ensures that the marginal effects of the primary factors of interest for study, in this case, the neighborhood characteristics, have accounted for these other sources of variability. The date, day of week, and time of day were used to calculate physical activity measures specific to day of week and time of day. Those 15-minute intervals occurring on weekend days (n=7506) between 9 am and 10 pm were used in these analyses.

Weather and Climate Data

Climate data were obtained from the National Oceanic & Atmospheric Administration’s National Climate Data Center [31]. We used unedited climatological data for Boston, MA, gathered from the weather station for days students wore accelerometers. Using the daily average temperature in Fahrenheit and total precipitation in inches, researchers calculated total precipitation and the percent deviation from historic average temperature for use in statistical analyses.

Neighborhood Characteristics

Objective Neighborhood Measures—Pedestrians for the most part travel through their local neighborhoods and communities along the street network. Consequently, the environment of an area within a walkable distance along the street network is likely to influence people’s decisions to walk. Levels of moderate and vigorous physical activity are thus associated with utilitarian transportation and recreational physical activity. For this study, we defined ten neighborhoods representing 800 m buffers around schools along the street network (excluding highways). These are areas where local level data could be aggregated by averaging to derive variables that might indicate neighborhood walkability. Students were assigned to a study neighborhood based on the school that they attended.

Following the work of Krizek [32], we adopted 150-meter grid cells as the basic unit of local level data for analysis. These grid cells allow for mapping of small area variability as well as aggregation of data for varied buffer specifications. Rather than averaging variables over a ¼ mile radius, we averaged data from grid cells within or intersecting the predefined 800 meter street network buffer distance to provide summary variables for each neighborhood. Grid cells with null values were set to 0 for the purpose of averaging. For several measures described below (i.e., block size, open space, household density) researchers used GIS methods comparable to other studies of neighborhood walkability among adults [33].

Average Daily Traffic

We obtained 1997 Mass Highway roads data to calculate a measure of Average Annual Daily Traffic (ADT) for study neighborhoods. These data are based on actual counts for major roads and are estimates where counts were not available. Data documentation indicate that of the total road length counts in our study areas, 0.4% were specified as estimates, 0.3% were counts from more than three years prior, and 3.5% were current counts or taken within the prior three years. Other information sources were either not documented (85.9%), or working counts for arterials (10.1%). Average daily traffic for each grid cell was calculated by taking the sum of the average daily traffic multiplied by length of the road segment divided by grid cell total length for each road segment within the cell.

Open Space

People may use open space directly for physical activity, or be likely to participate in physical activity in the neighborhood near open space because of improved aesthetics including green cover or other related factors. Using 2005 data from the MassGIS [34], we calculated the grid cell open space per person as the area of protected and recreational open space in square meters per person within 800 m of the center of the grid cell. These were then averaged to obtain neighborhood density of open space.

Housing Density

Housing units per acre are often indicative of local population densities. However, housing units rather than population units are regulated by zoning mechanisms and thus are potentially more amenable to intervention [35] For this study, researchers calculated network buffer housing density as total housing units as counted by the census per unit land area (excluding water).

Density of Employees in Destinations for Youth

We adapted a measure used in a prior study [32] characterizing local neighborhood accessibility using GIS in order to capture exposure to and density of local retail establishments that might be considered desirable destinations for young people (or adults) for errands or entertainment and recreation. This is one strategy to quantify and operationalize local land use patterns when municipal land use data are not available. Mixed land use has been identified as an important component of neighborhood walkability [36]. We purchased data on employers operating in our study towns in 1997 with fewer than 250 employees from INFOUSA (www.infousa.com) for the major Standard Industrial Classification (SIC) codes 53 (retail), 54 (food stores), 58 (eating and drinking places), 59 (miscellaneous retail), 78 (motion pictures), 83 (social services) and 84 (museums, art galleries & gardens) for the study city/towns. The employee limit of 250 was determined based on data availability and the desire to filter out larger businesses (e.g., Costco, Home Depot) whose presence would run counter to the desired measurement of neighborhood accessibility [32]. We used latitude and longitude of the employer to locate facilities relative to the 150m grid cells and the mid point of the category range of number of employees (i.e., 1–4, 5–9, 10–19, 20–49, 50–99, 100–249) to calculate the number of employees.

A small number of prior studies have examined count, attribute and positional error of commercial databases and methods for geocoding of addresses [37]. Boone and colleagues [38] found that compared with a field census of selected physical activity-related resources, a main source of commercial database error was an undercount of businesses in the database and that this undercount was not appreciably different in urban versus non-urban settings. To augment and validate our purchased data, researchers used existing data from a separately conducted census of youth physical activity programs in 2000 [39]. Researchers compared purchased data on relevant sub-categories of employer (YMCA and youth organizations) in one town and (in all city/towns) with internet and phone directory searches for social service agencies serving youth. These validation checks and subsequent verification via phone, resulted in the addition of two data points in one of the four city/town study areas. The final variable, employee density in youth destinations was calculated as the total employees in these categories per unit land area (excluding water).

Data Analysis

Neighborhood characteristics (i.e., average daily traffic, housing density, youth destinations: employee density) were divided by 1000 prior to inclusion in statistical models. We fit linear mixed models to the data to examine associations between neighborhood variables and objective physical activity levels measured on weekends. We defined two outcome variables for study: 1) TriTrac R3D vector magnitude averaged within each 15 minute (log-transformed) and 2) the proportion of the interval minutes in activity of moderate and vigorous intensity (MVPA) defined as at or above 1000 vector magnitude. This moderate and vigorous cut point for Tritrac-R3D had been used by other researchers [40] and was supported by an earlier analysis of Tritrac-R3D estimated energy expenditure from physical activity versus vector magnitude data with adjustment for basal metabolic rate calculations specific to age and sex of students [41]. Physical activities such as walking at a moderate pace are estimated to be of moderate to vigorous intensity among youth [42]. Average vector magnitude was log-transformed after initial model diagnostics assessment. Researchers also fit data using arc-sine and square root transformations and reviewed model fit and residual diagnostics to determine preferred analytical strategies. We used PROC MIXED in SAS (SAS 9.1, SAS Institute, Inc, Cary, NC). The model included fixed effects for time of day (in 15-minute intervals), day of week, sex, and race/ethnicity and intervention and control status. Student age in years and student BMI were included as continuous covariates. Analysis accounted for the nested data structure of repeated observations of physical activity levels within days, days of monitoring within students, and for students within school neighborhoods. Similar to prior analyses [27], we included a single random effect for each student accounting for correlation among activity level observations for that student, modeling the correlation of 15-minute activity level measurements within the same day and child and within school using a spatial power covariance matrix.

Results

A total of 152 students had physical activity data collected on weekend days in the 10 school neighborhoods (Table 1). The students had a mean age of 13.7 years and an average BMI of 22.1 and the distribution of students across the ten school neighborhoods was not equal. Students averaged approximately 6% if their time intervals in physical activity of at least moderate intensity over the course of the weekend day.

Table 2 details the distribution of neighborhood characteristics measured using GIS. Summary neighborhood measures of average daily traffic counts on roads ranged from 961–11,193 (median=3,185) while average employee density in youth destinations in neighborhoods ranged from 0 to 1087 (median =299). Neighborhoods also varied with respect to housing and open space density (Table 2). The neighborhood measure of employee density in destinations for youth was significantly correlated with measures of housing density ($r=0.93$, $p<.0001$) but not with the measure of traffic.

On weekends, neighborhood measures of employee density in youth destinations emerged as marginally significantly associated with physical activity levels (Table 3). In separate models, greater density of employees in destinations serving youth within the neighborhood was associated with proportion of time spent in MVPA ($\beta=3.96$, $p=0.050$) and marginally with overall log average vector magnitude (β=0.52, p=0.064), controlling for other student and weather variables. In the model predicting MVPA, female students were significantly less active than male students during the weekend; no statistically significant effects of age on activity levels were observed. The weather variables were not significantly associated with MVPA and were excluded from the final model (Table 3). However, total precipitation was directly associated with overall log vector magnitude on weekends (p=0.035) and the percent deviation from normal average temperature showed a marginally significant association. Neighborhood measures of average daily traffic, housing density and open space were not significantly associated with either physical activity outcome and are not shown.

Discussion

Neighborhood characteristics indicative of the density of likely destinations for youth, including commercial or recreational program destinations, emerged as significant correlates of physical activity on the weekends. The employment density findings may be indicative of mixed land use, a major component of local neighborhood walkability [36]. While transportation options for younger children may depend largely on the transportation mode of their primary caregiver [43], older children and adolescents may be allowed more freedom in mobility and thus may be sensitive to associated neighborhood environments. For children and adolescents, activities including walking and bicycling as part of daily travel can contribute to energy expenditure [5, 36, 44–46] and may contribute to cardiovascular fitness [5, 47]. Using the range of density of employees in destinations for youth observed in the present study, residence in the highest density neighborhoods would produce an estimated extra 30 minutes of moderate physical activity per day when compared with residence in areas with low density of employees in destinations for youth. This amount of moderate physical activity is equivalent to walking about 1.4 miles at moderate speed, expending an extra 121 kcal/day for an adolescent weighing approximately 45kg [42].

As children age into adolescence, their daily activities occur more frequently in social or community settings [20,21], suggesting the importance of addressing these particular settings when considering effective approaches to promoting physical activity in this age group. The findings presented in table 3 extrapolated to our data from study neighborhoods are consistent with prior time use studies [18] with regard to the importance of youth destination density. Additional prior research [11] suggests that for adolescents, urban form variables such as residence in an area with access to commercial or recreational destinations is associated with increased likelihood of reporting walking for transportation and walking at least one-half mile per day. Adolescence may represent a developmental period of expanding independence and mobility and promoting the use of physically active modes of transportation may be particularly timely in this age group.

A recent review of the effectiveness of interventions to promote physical activity among adolescents highlights the need for a multilevel approach that includes school and family as well as community involvement and policy and environmental changes [48]. Future research and policy foci that address both the type of physical activity (e.g., utilitarian transportation, recreational physical activity) and the characteristics of the settings of the physical activity will advance knowledge regarding the potential mechanisms of environmental impact on overall physical activity levels. For example, walking for transportation can be an important source of routine physical activity for youth and comparable in intensity with some types of structured physical activities [49]. Creating child-friendly settings around schools and youth-focused neighborhood destinations including programs, facilities and structured opportunities for recreational physical activity and providing skills to safely negotiate these environments may be important strategies to promote physical activity [14].

Limitations of this study merit consideration. Due to the lack of availability of home addresses for students, we were unable to determine where (or whether) a student lived within the neighborhood zone characterized by our study raising the potential for misclassification by neighborhood. Researchers are not able to determine whether the potential for neighborhood misclassification differed according to neighborhood characteristics, or how the potential for such misclassification may have influenced the study findings. Furthermore, the results observed may differ according to neighborhood buffer size used in analysis. The 800m buffer used may not adequately capture the potential range of usual destinations for all students or the place of residence for all students in our sample. Furthermore, using the street network to create buffers does not take into account other pedestrian routes that are not part of the street network. This is particularly a problem for large suburban neighborhoods with multiple potential connections to residential neighborhoods. The physical activity measures used cannot differentiate transportation-related physical activity from other types such as sport or exercise-related physical activity. Also, due to measurement protocols and monitor limitations, the measures will not adequately capture activities such as swimming or bicycling.

Additionally, researchers lacked data on perceived environmental characteristics from the students or their parents. Prior research supports an important role of perceived barriers to physically active transport that include crime, weather and distance [50], parental perceptions of traffic and personal safety concerns [4,18] and social environmental context [12]. Given the absence of actual traffic count data for many of the street segments, the lack of an observed statistically significant association between traffic and physical activity levels may be due to measurement quality. Data were not collected simultaneously in school neighborhoods therefore variations in absolute temperature are confounded with the neighborhood characteristics. We have used the variation from historic average to control for potential influences of weather on physical activity levels. This approach may not adequately control for variation due to seasonality. Researchers also lacked available data on individual household socioeconomic status, a factor that may influence access to both transportation resources and physical activity opportunities. Furthermore, students in the intervention groups may have been given information or skills to be physically active regardless of their environment. This study has a small number of study neighborhoods limiting the potential to identify non-linear or threshold effects. Characteristics of the school neighborhoods may also be confounded with neighborhood characteristics such as neighborhood socioeconomic status or factors also associated with the neighborhood's school. Future studies will be better equipped to address these current study limitations in their research design.

This study expands the existing literature by describing methods for objectively characterizing neighborhoods and weather patterns with publicly accessible data that are available in most areas of the US. It adds to the limited number of studies that test hypotheses regarding the impact of objectively measured local environments on physical activity behaviors of adolescents on weekends. A lack of desirable destinations within a walkable distance may adversely affect physical activity levels among adolescents. Providing convenient places within safe walking distance may lessen barriers to adolescent participation in physical activity on weekends.

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References

1. 2008 Physical Activity Guidelines Advisory Committee. [cited 2008 October 1] Physical Activity Guidelines Advisory Committee Report 2008. 2008. Available from: http://www.health.gov/PAGuidelines/Report/pdf/CommitteeReport.pdf
2. Troiano RP, Berrigan D, Dodd KW, et al. Physical activity in the United States measured by accelerometer. Med Sci Sports Exerc. 2008 Jan; 40(1):181–188. [PubMed: 18091006]
3. Ferreira I, van der Horst K, Wendel-Vos W, et al. Environmental correlates of physical activity in youth - a review and update. Obesity Reviews. 2007; 8(2):129–154. [PubMed: 17300279]
4. Davison K, Lawson C. Do attributes in the physical environment influence children's physical activity? A review of the literature. International Journal of Behavioral Nutrition and Physical Activity. 2006; 3(1):19. [PubMed: 16872543]
5. Davison KK, Werder JL, Lawson CT. Children's active commuting to school: current knowledge and future directions. Prev Chronic Dis. 2008 Jul.5(3):A100. [PubMed: 18558018]
6. Krizek KJ, Birnbaum AS, Levinson DM. A schematic for focusing on youth in investigations of community design and physical activity. American Journal of Health Promotion. 2004 Sep–Oct; 19(1):33–38. [PubMed: 15460099]
7. McMillan TE. Urban form and a child's trip to school: The current literature and a framework for future research. Journal of Planning Literature. 2005; 19(4):440–456.
8. Panter J, Jones A, van Sluijs E. Environmental determinants of active travel in youth: A review and framework for future research. International Journal of Behavioral Nutrition and Physical Activity. 2008; 5(1):34. [PubMed: 18573196]
9. Kerr J, Frank L, Sallis JF, et al. Urban form correlates of pedestrian travel in youth: Differences by gender, race-ethnicity and household attributes. Transportation Research Part D: Transport and Environment. 2007; 12(3):177–182.
10. McMillan TE. The relative influence of urban form on a child's travel mode to school. Transportation Research Part A: Policy and Practice. 2007; 41(1):69–79.
11. Frank L, Kerr J, Chapman J, et al. Urban form relationships with walk trip frequency and distance among youth. American Journal of Health Promotion. 2007; 21(4):305–311. [PubMed: 17465175]
12. McDonald NC. Travel and the social environment: Evidence from Alameda County, California. Transportation Research Part D: Transport and Environment. 2007; 12(1):53–63.
13. Kerr J, Rosenberg D, Sallis JF, et al. Active commuting to school: Associations with environment and parental concerns. Med Sci Sports Exerc. 2006 Apr; 38(4):787–794. [PubMed: 16679998]
14. Timperio A, Ball K, Salmon J, et al. Personal, familial, social and environmental correlates of active commuting to school. American Journal of Preventive Medicine. 2006; 30(1):45–51. [PubMed: 16414423]
15. Carver A, Timperio AF, Crawford D. Neighborhood Road Environments and Physical Activity Among Youth: The CLAN Study. Journal of Urban Health. 2008; 85(4):532–544. [PubMed: 18437579]
16. Copperman RB, Bhat CR. Exploratory analysis of children's daily time-use and activity patterns - Child development supplement to US panel study of income dynamics. Transportation Research Record. 2007; (2021):36–44.
17. Sener IN, Copperman RB, Pendyala RM, et al. An analysis of children's leisure activity engagement: examining the day of week, location, physical activity level, and fixity dimensions. Transportation. 2008 Aug; 35(5):673–696.
18. Copperman RB, Bhat CR. An analysis of the determinants of children's weekend physical activity participation. Transportation. 2007 Jan; 34(1):67–87.
19. Jago R, Baranowski T, Baranowski JC. Observed, GIS, self-reported environmental features and adolescent physical activity. American Journal of Health Promotion. 2006; 20(6):422–428. [PubMed: 16871822]
20. Jago R, Baranowski T, Harris M. Relationships Between GIS Environmental Features and Adolescent Male Physical Activity: GIS Coding Differences. Journal of Physical Activity & Health. 2006; 3(2):230–242.

21. Dowda M, McKenzie TL, Cohen DA, et al. Commercial venues as supports for physical activity in adolescent girls. Preventive Medicine. 2007 Aug–Sep; 45(2–3):163–168. [PubMed: 17673281]
22. Cohen DA, Ashwood JS, Scott MM, et al. Public parks and physical activity among adolescent girls. Pediatrics. 2006 Nov; 118(5):E1381–E1389. [PubMed: 17079539]
23. Norman GJ, Nutter SK, Ryan S, et al. Community design and access to recreational facilities as correlates of adolescent physical activity and Body-Mass Index. Journal of Physical Activity and Health. 2006; 3 Suppl 1:S118–S128.
24. Gortmaker SL, Peterson K, Wiecha J, et al. Reducing obesity via a school-based interdisciplinary intervention among youth: Planet Health. Arch Pediatr Adolesc Med. 1999 Apr; 153(4):409–418. [PubMed: 10201726]
25. Trost SG, McIver KL, Pate RR. Conducting accelerometer-based activity assessments in field-based research. Medicine and Science in Sports and Exercise. 2005 Nov; 37(11):S531–S543. [PubMed: 16294116]
26. Cradock A, Wiecha JL, Peterson KE, Sobol AM, Colditz GA, Gortmaker SL. Youth Recall and TriTrac Accelerometer Estimates of Physical Activity Levels. Medicine & Science in Sports & Exercise. 2004; 36(3):525–532. [PubMed: 15076797]
27. Cradock AL, Melly SJ, Allen JG, et al. Characteristics of School Campuses and Physical Activity Among Youth. American Journal of Preventive Medicine. 2007; 33(2):106.e101–113.e101. [PubMed: 17673097]
28. Morris JS, Arroyo C, Coull BA, et al. Using Wavelet-Based Functional Mixed Models to Characterize Population Heterogeneity in Accelerometer Profiles. Journal of the American Statistical Association. 2006; 101(476):1352–1364. [PubMed: 19169424]
29. Fairclough SJ, Butcher ZH, Stratton G. Whole-day and segmented-day physical activity variability of northwest England school children. Preventive Medicine. 2007; 44(5):421–425. [PubMed: 17320158]
30. Trost SG, Pate RR, Freedson PS, et al. Using objective physical activity measures with youth: how many days of monitoring are needed? Med Sci Sports Exerc. 2000 Feb; 32(2):426–431. [PubMed: 10694127]
31. National Climatic Data Center. [cited 2006 December 8] Local Climatological Data, Logan International Airport. 1997. Available from: http://www.ncdc.noaa.gov/oa/ncdc.html
32. Krizek KJ. Operationalizing neighborhood accessibility for land use-travel behavior research and regional modeling. Journal of Planning Education and Research. 2003 Spr;22(3):270–287.
33. Oakes JM, Forsyth A, Schmitz K. The effects of neighborhood density and street connectivity on walking behavior: the Twin Cities walking study. Epidemiologic Perspectives & Innovations. 2007; 4(1):16. [PubMed: 18078510]
34. MassGIS. [cited 2005 January 31] Protected and Recreational Open Space. 2005. Available from: http://www.mass.gov/mgis/osp.htm
35. Forsyth, A.; Koepp, J.; Oakes, JM., et al. Twin Cities Walking Study Environment and Physical Activity: GIS Protocols Version 2.0. Minneapolis, MN: Metropolitan Design Center; 2005.
36. Saelens BE, Handy SL. Built Environment Correlates of Walking: A Review. Medicine & Science in Sports & Exercise 2008. 2008; 40(7):S550–S566.
37. Zandbergen PA. Comments on Boone et al., "Validation of a GIS Facilities Database: Quantification and Implications of Error". Annals of Epidemiology. 2008; 18(10):823–824. [PubMed: 18922398]
38. Boone JE, Gordon-Larsen P, Stewart JD, et al. Validation of a GIS Facilities Database: Quantification and Implications of Error. Annals of Epidemiology. 2008; 18(5):371–377. [PubMed: 18261922]
39. Hannon C, Cradock A, Gortmaker SL, Wiecha J, El Ayadi A, Keefe L, Harris A. Play Across Boston: A Community Initiative to Reduce Disparities in Access to After-School Physical Activity Programs for Inner-city Youths. Preventing Chronic Disease. 2006 July.3(3):A100. [PubMed: 16776861]
40. Rowlands AV, Eston RG, Ingledew DK. Relationship between activity levels, aerobic fitness, and body fat in 8- to 10-yr-old children. J Appl Physiol. 1999 Apr; 86(4):1428–1435. [PubMed: 10194232]

41. Gortmaker, SL. The role of the physical activity environment in obesity among children and youth in the industrialized world. In: Chen, C.; Dietz, WH., editors. Obesity in childhood and adolescence. Philadelphia: Lippincott, Williams and Wilkins; 2002.
42. Ridley K, Ainsworth B, Olds T. Development of a Compendium of Energy Expenditures for Youth. International Journal of Behavioral Nutrition and Physical Activity. 2008; 5(1):45. [PubMed: 18782458]
43. McDonald NC. Household interactions and children's school travel: the effect of parental work patterns on walking and biking to school. Journal of Transport Geography. 2008; 16(5):324–331.
44. Faulkner GE, Buliung RN, Flora PK, et al. Active school transport, physical activity levels and body weight of children and youth: a systematic review. Prev Med. 2009 Jan; 48(1):3–8. [PubMed: 19014963]
45. Cooper AR, Andersen LB, Wedderkopp N, et al. Physical activity levels of children who walk, cycle, or are driven to school. Am J Prev Med. 2005 Oct; 29(3):179–184. [PubMed: 16168866]
46. Sirard JR, Riner WF, McIver KL, et al. Physical activity and active commuting to elementary school. Medicine and Science in Sports and Exercise. 2005 Dec; 37(12):2062–2069. [PubMed: 16331130]
47. Cooper AR, Wedderkopp N, Wang HAN, et al. Active Travel to School and Cardiovascular Fitness in Danish Children and Adolescents. [Miscellaneous Article]: Medicine & Science in Sports & Exercise October. 2006; 38(10):1724–1731.
48. Van Sluijs EMF, McMinn AM, Griffin SJ. Effectiveness of interventions to promote physical activity in children and adolescents: systematic review of controlled trials. BMJ. 2007 October 6.335(7622) 2007 :703-.
49. Mackett RL, Lucas L, Paskins J, et al. The therapeutic value of children's everyday travel. Transportation Research Part a-Policy and Practice. 2005 Feb–Mar; 39(2–3):205–219.
50. Centers for Disease Control and Prevention. Barriers to children walking and biking to school-United States 1999. MMWR. 2002; 51(32):701–704. [PubMed: 12206284]

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Table 1

Characteristics of the Participants and Weather Characteristics on Days of Monitoring

Student Characteristics		Weekend (n=152)	
Sex		***n***	%
	Male	89	59
	Female	63	41
Race and Ethnicity		***n***	%
	White	87	57
	Black/African American	15	10
	Hispanic	19	13
	Asian	18	12
	Other race/ethnicity	13	9
Neighborhoods		***n***	%
	1	5	3
	2	8	5
	3	9	6
	4	7	5
	5	4	3
	6	8	5
	7	13	9
	8	23	15
	9	22	14
	10	53	35
		Mean (SD)	
Student Age		13.7 (0.7)	
Student Body Mass Index		22.1 (4.8)	
Physical Activity Interval Summary Measures[a]		*PA intervals n=7506*	
Average Vector Magnitude		246.1 (316.1)	
Proportion of interval MVPA		5.7 (15.0)	
Proportion of interval Sedentary		72.4 (29.1)	

Weather Characteristics	Weekend Days (n=23)
	Mean (SD)
Temperature Deviation from Average (%)	−1.64 (21.00)
Total Precipitation (inches)	0.11 (0.17)

[a]Vector magnitudes at or above 1000 are classified as Moderate and Vigorous Physical Activity (MVPA), less than or equal to 250 vector

SD = Standard Deviation.

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Table 2

Characteristics of the Study Neighborhoods (n=10)

Variable	Mean	SD	Median	Minimum	Maximum
Count of Grid Cells in 800m Buffer	64	18.3	67	24	91
Housing Density	3083	1853.0	3363	383	6215
Average Daily Traffic	4544.0	3237.0	3185.0	960.5	11193.0
Density of Open Space	52.3	73.3	9.8	2.5	203.7
Youth Destinations: Employee Density	391.9	379.3	298.5	0.0	1087.0

SD = Standard Deviation.

All variables are within the 800 Meter Street network buffer; scaled variables are divided by 1000; Grid Cells = 150 m cells; Housing Density = Total housing units as counted by the census per unit land area (excluding water); Density of Open Space = Open space (m^2) per person within 800 m of the center of the grid cell; Destinations: Employee Density = Total Employees in Major Retail Subcategories per unit land area (excluding water); Youth Destinations: Employee Density = Total Employees in Youth Destinations per unit land area (excluding water).

Table 3

Associations between neighborhood variables and moderate-and-vigorous physical activity (MVPA) levels and (log) mean vector magnitude on weekend days

Outcome: Proportion of time in interval in MVPA
Model with Youth Destinations Variables

Effect	Estimate	SE	DF	t Value	Pr > |t|
Intercept	−4.66	7.15	133	−0.65	0.516
Body Mass Index (kg/m^2)	−0.16	0.09	149	−1.82	0.070
Age (years)	1.07	0.59	121	1.82	0.072
Female	−2.60	0.80	136	−3.24	0.002
Black	0.74	1.31	120	0.56	0.576
Hispanic	−0.59	1.27	136	−0.47	0.640
Asian Pacific Islander	−0.40	1.19	122	−0.34	0.734
Other Race/Ethnicity	−2.73	1.51	130	−1.81	0.072
Sunday	0.68	0.53	1466	1.27	0.203
Youth Destinations: Employee Density (scaled)	3.96	1.66	6.69	2.39	0.050

Outcome: (Log) Mean vector magnitude in interval
Model with Weather and Youth Destinations Variables

Effect	Estimate	SE	DF	t Value	Pr > |t|
Intercept	5.16	1.48	110	3.49	0.001
Body Mass Index (kg/m^2)	−0.03	0.02	110	−1.58	0.118
Age (years)	−0.0107	0.12	109	−0.09	0.932
Female	−0.26	0.16	108	−1.55	0.124
Black	0.08	0.28	102	0.27	0.788
Hispanic	0.04	0.26	108	0.14	0.892
Asian Pacific Islander	0.29	0.25	99.6	1.13	0.260
Other Race/Ethnicity	−0.23	0.31	111	−0.75	0.456
Sunday	−0.01	0.06	1125	−0.09	0.928
Temperature Deviation from Average (%)	0.005	0.003	707	1.79	0.074
Total Precipitation (inches)	0.49	0.23	1168	2.11	0.035
Youth Destinations: Employee Density (scaled)	0.52	0.28	103	1.87	0.064

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MVPA = Moderate and Vigorous Physical Activity; SE = Standard Error; DF = Degrees of Freedom (Satterthwaite's approximation).

Referent categories are male, white non-Hispanic, Saturday, and time of day 12:15 – 12:29 pm; regression estimates for the remaining 51 indicators for 15-minute time of day intervals are not shown; variables for body mass index, age, temperature deviation from average, total precipitation, and employee density of youth destinations are modeled as continuous variables; employee density of youth destinations variable is a rescaled variable (divided by 1000).