Published in final edited form as:
Health Place. 2012 January ; 18(1): 55–62. doi:10.1016/j.healthplace.2011.08.020.

Out and about: Association of the built environment with physical activity behaviors of adolescent females

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Abstract

Locational data, logged on portable GPS units and matched with accelerometer data, was used to examine associations of the built environment with physical activity and sedentary behaviors of adolescent females. In a sample of 293 adolescent females ages 15 to 18 years old in Minneapolis and San Diego, the built environment around each GPS point and its corresponding sedentary, light, and moderate-to-vigorous intensity physical activity were examined using random intercept multinomial logistic regression models. The odds of higher physical activity intensity (3-level outcome: sedentary, light, MVPA) were higher in places with parks, schools, and high population density, during weekdays, and lower in places with more roads and food outlets. Understanding the places where physical activity and sedentary behaviors occur appears to be a promising strategy to clarify relationships and inform policy aimed at increasing physical activity and reducing sedentary behaviors.

Keywords

built environment; adolescents; physical activity; accelerometer; GPS; sedentary behavior

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Introduction

Obesity and sedentary behaviors among children and adults are a pressing public health concern (Flegal et al., 2010). In a 34-country study, less than 20% of school-children met recommendations for physical activity (Guthold et al., 2010). While the prevalence is similar for self-reported data in the United States (CDC, 2010), objectively measured physical activity suggests that only 12% of U.S. adolescents meet current guidelines to accumulate 60 minutes of at least moderate-intensity activity on most days of the week (Troiano et al., 2008). Furthermore, physical activity decreases continuously as children age (Nader et al., 2008), with the lowest levels occurring in late adolescence (Troiano et al., 2008). There is growing interest in identifying built environment barriers and supports for physical activity in children (Cooper et al., 2010; van Sluijs et al., 2008). Modifying the built environments where children live, attend school, and play may be a promising strategy to increase their physical activity (Tester, 2009).

Studies to date have identified the presence of parks (Cradock et al., 2009; Frank et al., 2007; Grow et al., 2008) and having physical activity facilities close to home (Dowda et al., 2007a; Scott et al., 2007b) as being positively associated with walking and moderate- to vigorous-intensity physical activity (MVPA) in adolescents. Contrary to the literature on adults, the population density and street design of the home neighborhood have been less consistently associated with physical activity of adolescents (Cradock et al., 2009; Evenson et al., 2010). Other studies have examined associations between built environments and walking and bicycling to school. Nationally, distance to school is negatively associated and population density is positively associated with walking to school (McDonald, 2008a). High diversity of land uses (Larsen et al., 2009; Voorhees et al., 2009), and pedestrian-oriented street design (Bungum et al., 2009; Hume et al., 2009) around residents' home and schools also have been associated with more walking to school.

Because adolescent females are less physically active than adolescent males (Sallis et al., 2000; Troiano et al., 2008), understanding the factors that differentially explain physical activity is a promising strategy to inform policy and improve population health. In addition, differences between adolescent females and males in perceptions and behaviors suggest that understanding environmental supports and barriers for each group is warranted. Adolescent girls prefer different activities, participate in physical for different reasons, and tend to face different barriers than adolescent boys (Bradley et al., 2000; Kuo et al., 2009; Tappe et al., 1989). For example, a study of 12^{th}-grade adolescent females of 17.7 years of age on average, showed that nearly one-third of the total physical activity of those employed occurred at work (Dowda et al., 2007b). Another study revealed that focusing on the area around home in order to examine environmental exposures may be inadequate because adolescent females spend 33% of their awake time more than 1 km from their homes (Wiehe et al., 2008). The importance of these exposures is likely to vary by day of week, because adolescent girls walk more and are more active at moderate and vigorous intensities on weekdays than on weekends (Beets et al., 2010; Treuth et al., 2007). Thus, considering outdoor areas where adolescent females spend time can be helpful in understanding the built environment characteristics that facilitate or act as barriers to physical activity.

The advent of global positioning systems (GPS), which record locational information over time, has enabled further examination of where physical activity occurs and where it does not (Jones et al., 2009; Wolf, 2004). One pilot study with adults using GPS and accelerometers concurrently suggested that MVPA (as defined by Swartz et al., (2000)) in bouts of 10 minutes or more in duration were more likely to occur in areas with environmental supports (Rodriguez et al., 2005). In another study, children ages 10 to 11 were more likely to engage in MVPA (≥3200 accelerometer counts per minute, regardless of duration) if they were on or next to parcels that contain green space or parks rather than indoor spaces or other outdoor spaces (Wheeler et al., 2010). Despite this early evidence, there is a paucity of studies among youth examining the objectively assessed built environment context within which physical activity and sedentary behavior take place. Identifying the context for physical activity and sedentary behaviors among youth is critical for developing a comprehensive understanding of the possible effectiveness of future interventions.

In this study, we examine associations between the outdoor built environment and MVPA intensity as measured with passive, portable accelerometry and GPS in adolescent females living in two metropolitan areas in the U. S. Our primary hypothesis was that the presence of parks, physical activity facilities, longer road length, and higher population density would be positively associated with higher physical activity intensity behaviors. A secondary hypothesis was that physical activity was lower during weekend days, relative to weekdays and that it would decline from one year to the next one.

Methods

The socioecologic framework (Stokols, 1992) motivates the current study. From the socioecologic perspective, the built environment is a factor that, together with macro-, interpersonal-, and individual-level factors, contributes to and can be influenced by physical activity behavior (Sallis and Owen, 1997). In contrast to prior research, we utilize point-by-point accelerometer and GPS information to associate the intensity of physical activity and sedentary behaviors outside of home and schools with the built environment surrounding each point.

Data sources

Participants aged 13.2 to 14.9 years enrolled as 8^{th}-grade controls in the multi-site TAAG (Trial of Activity for Adolescents Girls) Study from the San Diego and the Minneapolis/St. Paul (Minneapolis from here on) metropolitan areas were invited to participate in a longitudinal follow-up study. These sites comprised 2 of the original 6 sites in the TAAG Study (Stevens et al., 2005) exhibiting high participation and retention rates at each measurement time period and representing geographically and ethnically diverse populations. We contacted 632 eligible adolescent females attending 7 different high schools. After obtaining parental consent and their own assent, we enrolled 303 respondents, about half at each site. A power analysis to detect medium effect sizes (0.5) of the main study outcomes (BMI and met-weighted moderate and vigorous physical activity trajectories in the cohort) suggested that a final sample size of 200 girls would be appropriate. Assuming attrition from one year to the next due to transiency, school drop outs, refusal to participate in follow-up measures, and other causes of loss-to-follow up, we aimed for recruiting 300 participants, 150 girls per site.

Participants were asked to wear off-the-shelf Foretrex 201 portable (83.8 × 43.2 × 15.2 mm) GPS units (Garmin Ltd., Olathe, KS). These units have been shown to have adequate accuracy and reliability in free-living conditions (Rodriguez et al., 2005). An internal non-volatile memory card provided the unit with the capacity to store 10,000 points before the data require downloading. The units were set to record the positional coordinates of their location at 60-second intervals with the Wide Area Augmentation System (WAAS) disabled. The map datum used was World Geodetic Survey 1984 and the position format was latitude and longitude in degrees and minutes (HD° MM’).

Concurrently with the GPS unit, participants wore an accelerometer: the dual-mode ActiGraph model 7164, formerly known as the CSA (Computer Science and Applications, Pensacola, FL). Previous studies have demonstrated the ActiGraph to be a technically reliable instrument, able to detect differing levels of physical activity intensity (Metcalf et al., 2002; Welk et al., 2004). Accelerometers were set to record activity in 30-second epochs to maintain consistency with the methods used in the TAAG Study (Treuth et al., 2004).

Participants were asked to wear the units for two different time periods. About one-half of the sample in each city wore the units for the first time in 10th grade, and a second time in 11th grade. The other half of the sample wore the units for the first time in 11th grade, and a second time in 12th grade. Participants were randomly selected and similarly assigned into either the 10/11th grade or the 11/12th grade groups. Mean follow up time was 347 days. Each time, participants were asked to wear the GPS unit and accelerometer during all waking hours for six consecutive days, except when showering, bathing, swimming, or engaging in other activities that would result in submerging the units in water. They were instructed to wear the ActiGraph unit on the right hip (Schmidt et al., 2003; Swartz et al., 2000) and to wear the GPS units on either their wrists or on a belt around their waists, and to charge the GPS unit overnight every night. At the end of each week, study staff retrieved the devices, and downloaded the data.

Data preparation and merging

Accelerometer data were aggregated to total per-minute counts (as opposed to 30 seconds). A customized computer program was used to clean and summarize accelerometer data. A participant was considered not to be wearing the accelerometer if 20 or more consecutive minutes had zero counts as indicated by Mâsse et al (2005). We defined, *a priori*, counts exceeding 15,000 for 5 minutes or more as outliers, but none were identified. A day was considered valid if the accelerometer was worn for more than 8.3 hours on a weekend day or 10.6 hours on a week day, consistent with the TAAG Study (Catellier et al., 2005), and if that day contained at least one GPS data point to ensure that the GPS unit was turned on that day. Each day of data was evaluated for wearing time below the minimum wearing time threshold and if positive, the GPS and accelerometer data from that day were excluded from analysis.

We merged each participant's accelerometer data with the corresponding GPS data according to the date and time information in each unit, so that each GPS point had a corresponding accelerometer count. We excluded GPS points without accelerometer data and accelerometer minutes without GPS data. Thus, each GPS point contained information about the intensity of physical activity associated with its accelerometer count. To avoid misclassifying behaviors that occurred while inside home or school, any point falling in or within 60 meters (200 feet) of school property or the home of a participant was excluded from the analysis. This is because being in a building close to a window may result in positional data being logged. Another study showed that errors of 50 meters were unlikely with these units once a unit was set in place in the view of satellites (Rodriguez et al., 2005). Only points within San Diego County (for the San Diego site) and Ramsey, Dakota, Carver, Hennepin, Anoka, and Washington Counties (for the Minneapolis site) were considered for analysis.

Outcome variable

The outcome variable was each point's physical activity intensity, classified using counts as sedentary (<100 counts/min), light (>=100 to < 3000 counts/min), or moderate or vigorous (>=3000 counts/min). These thresholds were specific to adolescent girls (Treuth et al., 2004).

Built environment exposures

The built environment within a 50-meter circle drawn around each GPS-accelerometer point was measured by calculating street density (from TIGER 2009 files), the number of food outlets, and the presence of parks, schools, physical activity facilities, and fast food restaurants. Because slow and brisk walking speeds for adolescent females range between 66.6 and 93.3 meters per minute, a distance of 50 meters would limit the potential lack of independence of the built environment characteristics between consecutive points. Physical activity facilities include businesses that support physical activity such as bowling alleys, dance studios, swimming pools, yoga studios, exercise facilities, and sports clubs (Dowda et al., 2007a). Data on food outlets and fast food restaurant locations for San Diego were provided by the Neighborhood Impact on Kids Study (Saelens et al., 2010). In Minneapolis, food-related data originated from city and county health department inspection records. In both sites, park and food-related data were updated with direct observations for select areas of the city. The only exception to the 50-meter circle is population density, which was calculated for the US Census block in which each point fell (U.S. Bureau of the Census, 2000). All other data were collected from county and municipal sources by an ancillary study to the original TAAG Study.

Participant-specific home neighborhood characteristics

To account for the possibility that participants who live in neighborhoods with certain characteristics could have similar physical activity behaviors, we included variables measuring the built environment of each person's home neighborhood. The home neighborhood was defined as the area within an 800-meter circle drawn around each participant's home location, an area that has been used in other studies to define person-centered neighborhoods (Nagel et al., 2008; Rundle et al., 2009; Scott et al., 2007a). Gross population density, the ratio between jobs and households, distance to nearest park (miles), distance to each participant's school, intersection density, road density, and percentage of households under the federally designated level of poverty were measured. Home neighborhood variables came from the US Census Bureau (Summary Files 1 and 3, and the Census Transportation Planning Package, for the year 2000), except the park and school information, which was collected by the TAAG Study and detailed in Cohen et al. (2006).

All built environment measures were derived using ArcGIS 9.2 (Environmental Systems Research Institute Inc., Redlands CA, 2006). When a circle around a GPS point or a participant's home was not fully contained within a census polygon, the data were assigned in direct proportion to the area of the polygon contained within the circle.

Socio-demographic measures

Girl-level data on age, race/ethnicity, and whether the family qualified for free or reduced price lunch were also included. Age and race and ethnicity (classified as Hispanic, White, Asian – including Native Hawaiian or Pacific Islander, Black, and Other) were reported by the student in 8^{th} grade. The free or reduced price lunch variable was student reported in 10^{th} or 11^{th} grade and categorized as "yes" versus "no or don't know."

Statistical analysis

For the statistical analyses, the unit of observation is the GPS/accelerometer point, with multiple points per participant. Random intercept models using the generalized linear latent and mixed models (GLLAMM) extension (Skrondal and Rabe-Hesketh, 2003) with a multinomial logit link function, a binomial family distribution, and the adaptive quadrature were used to analyze the three-level categorical outcomes (sedentary, light, and MVPA) in Stata 11.2 (Stata Corp, 2011). These models appropriately accounted for the clustered data structure of repeated measurements for each study participant. Given differences in environmental contexts for the two sites, models were estimated separately for San Diego and Minneapolis. In all cases, sedentary behavior was used as the reference category. Among the built environment and individual-level variables considered, only gross population density and intersection density exhibited high collinearity (variance inflation factor greater than 4). As a result, intersection density was excluded from all analyses. We entered the GPS/accelerometer point built environment variables together into a model that adjusted for the home neighborhood environment variables, and also adjusted for fixed effects of the measurement time period (1 or 2) and whether the point was during a weekend or weekday.

Results

Description of the cohort

A total of 293 participants had a least one valid day of data during any of the two measurement periods (148 in San Diego and 145 in Minneapolis). Of these, 21 had observations only in the first measurement period and 7 had observations only in the second measurement period (265 participants were observed in both measurement periods). Table 1 summarizes socio-demographic characteristics of the sample by site. The mean age of the sample when first observed in the current data was 16.3 years and the racial/ethnic makeup of the sample was 53% White, 28% Hispanic, 8% Asian, 6% Other, and 5% Black. The racial/ethnic makeup differed by site, with the majority of girls from Minneapolis identifying as White and the majority of students from San Diego identifying as Hispanic. For the regression models, the Asian, Black, and Other race/ethnicity categories were collapsed into a single ‘other’ category. Overall, 26% of the participants’ families qualified for free or reduced price lunch.

Participants wore the accelerometer for an average of 13.2 hours/day (SD 1.1 hours) and engaged in an average of 20.5 minutes of MVPA per day (online Table 1). When comparing between sites and measurement periods, San Diego participants engaged in 21.1 and Minneapolis participants engaged in 21.0 minutes of MVPA when first measured. Similarly, participants engaged in 4.2 minutes per day of MVPA time in bouts of 10 minutes or more, with San Diego participants being slightly more active than Minneapolis participants. For the second measurement, MVPA time declined nominally to 20.9 minutes per day among San Diego participants, and to 19.1 minutes per day for Minneapolis participants.

Combining the GPS and accelerometer data led to losses of accelerometer data, partly because GPS points may not recorded due to obstructions of the satellites. Comparisons of the accelerometer data with and without GPS information (not shown) suggest that more than half of the MVPA time in bouts has GPS data attached to it, which is consistent with similar losses identified in other studies elsewhere (Jones et al., 2009; Rodriguez et al., 2005). The comparisons also indicate that the loss of accelerometer data is greater for MVPA time that is not in a bout, as expected.

Regarding the GPS-accelerometer points, we had a total of 156,469 points that met eligibility criteria for analysis, of which 8,744 had MVPA, 72,702 had light physical activity, and 75,023 were sedentary. Although we attempted to use all these points, we ran into computational constraints with ArcGIS, which was unable to calculate the 50-m built environment measures for more than 150,000 points. The compromise was to use random, equal shares sampling. This involved assigning a random number to each point, sorting the number from smallest to largest, and selecting the first 8,744 light, and the first 8,744 sedentary points. As a result, all 8,744 points with MVPA were included, and light and sedentary points were randomly sampled to reach 8,744 points each. Thus, 12.0% of light and 11.7% of sedentary points were sampled. Of the resulting 26,232 points (8,744 × 3), 23,654 (90.2%) had full built environment data (88.0% sedentary, 90.0% light, and 93.1% MVPA) and were used for analysis. Table 2 provides the descriptive statistics of the outcome and built environment variables by site. In San Diego, the built environment around each GPS/accelerometer point had higher population density, more road length, and more food and fast food outlets; it also was more likely to contain a school than in Minneapolis. However, the Minneapolis points were more likely to include physical activity facilities and parks than the San Diego points.

The built environment of the home neighborhood suggested that girls in San Diego live in areas that appear to be more urbanized than the girls in Minneapolis, since they have higher population density, presence of schools closer to home, larger distance to the closest park, and a higher percentage of the households under the federal poverty level. Although the jobs-housing ratio was greater for Minneapolis than San Diego, this was due to an observation with a high value. Otherwise, San Diego's ratio of jobs to houses is greater than the Minneapolis ratio.

Model results

To examine the first hypothesis, adjusted associations of the parks, physical activity facilities, road length, and population density variables measuring the built environment around each point with the three levels of physical activity intensity are shown in Table 3. In San Diego, the presence of a park within the 50-meter buffer of each GPS/accelerometer point was associated with 41% higher odds of light activity (odds ratio (OR) 1.41), while higher population density (OR 1.01) and the presence of schools (OR 1.69) were associated with higher odds of MVPA compared to sedentary behavior. By contrast, road length (OR 0.38) and number of food outlets (OR 0.73) were associated with lower odds of MVPA.

In Minneapolis, relative to points with sedentary behavior, higher population density (OR 1.04), and the presence of parks (OR 1.86) and schools (OR 2.14) within the 50 meter buffer of each point had higher odds of MVPA, but not of light activity. Road length (OR 0.43) was associated with lower odds of MVPA, and the number of food outlets (OR 0.71) was associated with lower odds of MVPA.

Consistent with our secondary hypothesis, in San Diego, points recorded during weekends had lower odds of light and MVPA (OR 0.87 and OR 0.39, respectively). In Minneapolis, weekend points were associated only with lower odds of MVPA (OR 0.62). In San Diego, there was no decrease in physical activity intensity over approximately one year in time. In Minneapolis, however, in the second measurement period the odds of identifying a point with light activity decreased by a factor of 0.54, and the odds for MVPA decreased by 0.51, relative to sedentary behavior.

Discussion

We studied the context within which physical activity and sedentary behavior occurs by examining associations between accelerometer-identified activities and the built environment at the associated GPS location. This minute-by-minute examination of activities was made possible by the concurrent use of GPS units and accelerometers. Our results for MVPA among the sample of adolescent females in the San Diego and Minneapolis areas have salient commonalities. Points that occurred in areas with higher population density, with schools present, and in Minneapolis with parks present were more likely to have MVPA compared to sedentary behavior. We also found that MVPA was less likely to occur during weekends, which is consistent with other studies that have found lower MVPA during weekends (Beets et al.; Treuth et al., 2007). By contrast, points with higher road length or with food outlets nearby were negatively associated with MVPA.

The relevance of school presence is consistent with other studies finding that schools can be an important physical activity resource for adolescents, even during non-school hours (Cradock et al., 2009; Scott et al., 2007a). Since points within 60 meters of each girl's own school were excluded from the analysis, the results highlight the importance of other schools as physical activity resources. Similarly, among adolescents, parks have been positively associated with physical activity (Cohen et al., 2006; Frank et al., 2007; Grow et al., 2008) and a study of children 9-10 years of age in Norfolk, England found that 7% of the physical activity time in bouts (of at least 5 minutes) occurred in parks (Jones et al., 2009).

Accordingly, the lack of significance of parks in the San Diego site is somewhat unexpected. A study did not find associations between access to green space and MVPA among girls aged 10 and 11 in the United Kingdom (Wheeler et al., 2010), while another study found that only 1.9% of the daily physical activity of 5-10 year old children in New Zealand occurred in parks or playgrounds (Quigg et al., 2010). Descriptive statistics for the home neighborhoods of participants (Table 2) suggest that, on average, San Diego girls have parks that are 30% further away than Minneapolis girls. Furthermore, because the San Diego girls live in areas that are more compact with higher population density, it may be that the parks close to each girl's home are qualitatively different at the two sites for example in their offerings of facilities and services, which have shown to be important for children (Epstein et al., 2006). Consistent with prior evidence (Wolch et al., 2011), providing larger parks, with better facilities and offerings may be more difficult in dense urban environments than in suburban ones.

Our results on population density and roads contribute to evidence among youth populations that has been contradictory. In some studies, population density has been positively associated with physical activity generally, and walking to school specifically (McDonald, 2008b), while other studies (Cradock et al., 2009) have not identified an association. Together, the results for parks, schools, and population density support prior suggestions to intervene in those built environments to increase the physical activity of youth. There may be an added benefit. Parks, schools and population density also have been associated with higher physical activity in adult populations. Thus, changes to these environments may have physical activity benefits across population subgroups. This is particularly important for youth, as planners tend to give lower priority to working with youth and assessing their needs throughout the planning process (Grant and Manuel, 2011).

The results for the road length variable were unexpected, suggesting more sedentary behaviors as the road length around each point was longer. It is possible that our findings reflect the fact that individuals are largely sedentary when traveling by motorized transportation modes (such as car or bus), yet they are exposed to significant roads around them. Furthermore, our measure of physical activity was specific to the intensity, and not the type of physical activity. Yet, road infrastructure appears to be important in particular types of physical activity. Although some studies have found no association between overall physical activity among youth and the road network (Evenson et al., 2010), others have suggested that the likelihood of walking to school increases with higher road connectivity (Clifton and Kreamer-Fults, 2007) and smaller blocks (Voorhees et al., 2009).

For light activity relative to sedentary behavior, the results were inconsistent across sites. One reason for the inconsistency is that there may be a wider, context-specific variety of built environment characteristics that can be associated with light intensity physical activity, as compared with built environments and their association with MVPA. As with MVPA, road length around each point was negatively associated with light activity, but only in Minneapolis. The coefficient for the San Diego sample did not reach statistical significance. It is also likely that we have residual confounding; and there may be other unobserved contextual and individual characteristics associated with the exposures and the behaviors.

The results also suggest less MVPA when a point was surrounded by one or more food outlets, but not specifically for fast food outlets. These results may be capturing sedentary behaviors, when participants visit malls with outdoor areas (like strip malls), or restaurants with outdoor seating, or as suggested previously when they are traveling by car or bus through commercial areas.

We also found that for participants in Minneapolis, the odds of engaging in MVPA decreased from the first to the second measurement time or approximately one year apart. Coefficients were similar in direction and magnitude for San Diego participants but they did not reach statistical significance. Although the magnitude of the decrease is difficult to identify, the difference is consistent with documented decreases in physical activity as adolescent females age (Kimm et al., 2002; van Mechelen et al., 2000). Using cross-sectional data that included the cohort in the present study, Pate (2009) estimated decreases of 4% per year in MVPA between 6th and 8th grade. Also using a cross-sectional sample but at a national level, Troiano (2008) found 20% lower MVPA minutes for 16-19 year olds relative to the 12-15-year-olds.

Most of the empirical evidence against which we interpreted our findings came from studies that examined the home neighborhood relative to overall levels of physical activity. In our study, however, the data and analysis focused on minute-by-minute physical activity and where it occurred. Several reviews have made a strong conceptual and practical case for examining physical activities and the contexts in which they occur (Giles-Corti et al., 2005; McCormack et al., 2004; Owen et al., 2004). As shown here, physical activity takes place in diverse settings, and therefore understanding the type and location of physical activity, and matching it to the characteristics of location, promises to improve measurement and clarify relationships.

To our knowledge, only one other study has followed a similar approach of merging accelerometer and GPS data to analyze it on a point-by-point basis, partly because until recently very few studies have had access to concurrent GPS and accelerometer data. Using a 4-day sample of 10- and 11-year-old youth in Bristol, United Kingdom, Wheeler et al. (2010) examined whether points in green areas were more likely to have high activity counts than outdoor points not in green spaces. For girls they did not find an association, but when boys were in green spaces they were more likely to engage in MVPA.

Examining minute-by-minute activity and locational data is not without challenges. It may be preferable to use all the sedentary and light activity observations instead of the random sampling performed. However, given ArcGIS’ computational constraints, we opted for using random sampling to achieve equal shares. In most situations such a sampling approach can represent an optimal or near-optimal design (Imbens, 1992). A related concern is that focusing on the accelerometer count of points may result in considerable noise; it is reasonable to expect some points with high counts within a set of consecutive sedentary points. To examine this concern further, we also estimated the statistical models using a modified sample, which included only points that were part of MVPA bouts. An MVPA bout was defined as at least 10 consecutive points (minutes) at or exceeding the threshold for moderate activity (>=3000 counts/min) allowing for 30% of those points to be under the threshold. For example, in a 12-minute MVPA bout, 4 minutes could be under the threshold level. Light and sedentary points that were not part of MVPA bouts were sampled randomly in numbers equal to the MVPA sample. Overall results (not shown) were similar to those presented here but model fit deteriorated slightly.

There are several limitations in the study. First, only points with GPS locations were considered. It is possible that outdoor points in urban canyons or under heavy tree canopy may obstruct the GPS unit's view of satellites and therefore no positional data would be recorded. Second, omitting points within 60 meters from home and school may inadvertently exclude legitimate outdoor points close to home or school (e.g., gardening).

Third, we used actual un-imputed data. It is possible to impute accelerometer data (Catellier et al., 2005). However, we chose to use actual rather than imputed data as imputation algorithms for data from portable GPS units have not been developed. Fourth, our results may be sensitive to the definition of area around each point. We used a 50-meter radius on the basis that such a distance would be covered in one minute by adolescent females walking slowly (at 2.5 mph) (Treuth et al., 2004). At least one other that examined environmental conditions around GPS points used a similar buffer (Troped et al., 2010). We also estimated models for built environment characteristics within 80 meters of each point and results were largely consistent with those shown here. Fifth, some of our GIS data was not contemporaneous with the behaviors observed, thereby introducing potential measurement error. Sixth, there are several omitted variables such as individual (e.g., personality), inter-personal (e.g., family characteristics and social supports), and community-wide factors (e.g., weather). According to the socioecologic framework, these variables are relevant in explaining physical activity and sedentary behaviors. Finally, although we examined the occurrence of outdoor physical activity, we did not examine the types of activity that participants were engaging in and we omitted activity that occurred indoors such as in malls or gyms. Further examination of type of physical activity and the indoor locations where it takes place may yield additional clues regarding the potential importance of the built environment as support or barrier to active lifestyles.

Our results in a sample of adolescent females provide suggestive evidence to support the view that the built environment within which physical activity occurs is important for understanding behaviors. We found that higher population density, the presence of schools, and the presence of parks to be positively associated with light and MVPA, while longer road length and the higher number of food outlets were negatively associated with light and MVPA. We also found that MVPA was less likely to occur during weekends. These findings are consistent with the need for built environments that facilitate physical activity for adolescents. Differences in the results by study site also provide some evidence to support the view that the built environment appears to matter differently for physical activity depending on context. Further research may examine whether in more urban settings, certain built environment attributes may be more or less relevant for physical activity than in suburban settings.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

Acknowledgments

This study was supported by the National Institutes of Health (NIH), National Heart Lung and Blood Institute grants # R01HL71244, U01HL-66845, HL-66852, HL-66853, HL-66855, HL-66856, HL-66857, and HL-66858. The content is solely the responsibility of the authors and does not necessarily represent the official views of the NIH.

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Table 1

Individual-level characteristics of adolescent females included in analyses

	San Diego, CA						Minneapolis, MN					
	n	**%**	**Mean**	**SD**	**Min**	**Max**	**n**	**%**	**Mean**	**SD**	**Min**	**Max**
Age (years at measurement time period 1)	148		16.29	0.49	15.30	17.60	145		16.37	0.44	15.60	17.30
Race												
Hispanic	78	52.70					5	3.45				
White	37	25.00					119	82.07				
Asian	12	8.11					11	7.59				
Black	9	6.08					5	3.45				
Other	12	8.11					5	3.45				
Free lunch eligibility (yes/don't know=1, at measurement time period 1)	148		0.36	0.48	0	1	145		0.17	0.37	0	1

Table 2

Built environment characteristics near GPS/accelerometer points and in the home neighborhood of adolescent females†

	San Diego, CA						Minneapolis, MN					
	n	%	Mean	SD	Min	Max	n	%	Mean	SD	Min	Max
Built environment around each point (50 m)												
Population density (1000s per square mile)	13,916		6.1	7.1	0.0	2,32.9	9,738		2.0	3.2	0.0	63.0
Road length (miles)	13,916		0.1	0.2	0.0	2.2	9,738		0.1	0.1	0.0	1.2
Presence of physical activity facilities	31	0.2					53	0.5				
Presence of parks	789	5.7					753	7.7				
Presence of schools	444	3.2					169	1.7				
# of food outlets												
0	12,876	92.5					9,434	96.9				
1	560	4.0					147	1.5				
2	176	1.3					70	0.7				
3	114	0.8					47	0.5				
4 or more	190	1.4					40	0.4				
Presence of fast food outlets	83	0.6					37	0.4				
Home neighborhood built environment (800 m)												
Population density (1000s per square mile)	148		5.9	1.7	1.2	11.2	145		1.8	1.3	0.2	8.9
Job-housing ratio	148		0.4	0.2	0.1	1.1	145		0.9	0.8	0.1	4.9
Distance to school (miles)	148		1.8	1.3	0.2	8.7	145		3.5	2.2	0.2	8.9
Distance to park (miles)	148		0.4	0.2	0.0	1.1	145		0.3	0.3	0.0	1.6
% households in poverty	148		7.9	3.3	2.1	28.7	145		3.4	2.2	0.0	15.6
Other variables												
Measurement time period												
1	7,094	51.0					4,706	48.3				
2	6,822	49.0					5,032	51.7				
Weekend day	4,134	29.7					3,568	36.6				
Outcomes												
Sedentary (<100 counts/min)	4,515	32.4					3,185	32.7				
Light (>=100, < 3000 counts/min)	4,592	33.0					3,217	33.0				

	San Diego, CA						Minneapolis, MN					
	n	**%**	**Mean**	**SD**	**Min**	**Max**	**n**	**%**	**Mean**	**SD**	**Min**	**Max**
Moderate or vigorous (> 3000 counts/min)	4,809	34.6					3,336	34.3				

†The sample size (n) for the built environment variables around each point, the measurement period, and the outcomes represents the number of GPS/accelerometer points examined. There are many points to each participant. The sample size (n) for the home neighborhood built environment variables represents the number of participants in the study, as these are measured at the participant level. Home neighborhood values shown are for measurement time period 1.

Table 3

Adjusted odds ratio of minute-by-minute physical activity intensity (in three levels) associated with the built environment around each point†

	San Diego, CA‡				Minneapolis, MN‡			
	Light vs. Sedentary		Moderate or Vigorous vs. Sedentary		Light vs. Sedentary		Moderate or Vigorous vs. Sedentary	
	OR	95% CI	OR	95% CI	OR	95% CI	OR	95% CI
Built environment around each point (50m)								
Population density (1000s per sq. mile)	1.00	[0.99,1.00]	1.01	[1.00,1.02] *	1.00	[0.98,1.02]	1.04	[1.02,1.07] *
Road length (miles)	0.81	[0.62,1.05]	0.38	[0.28,0.51] *	0.43	[0.25,0.74] *	0.43	[0.25,0.74] *
Presence of physical activity facilities	1.11	[0.48,2.59]	0.28	[0.07,1.08]	2.15	[0.97,4.76]	1.53	[0.65,3.59]
Presence of parks	1.41	[1.15,1.74] *	0.80	[0.64,1.00]	0.98	[0.78,1.24]	1.86	[1.51,2.31] *
Presence of schools	1.18	[0.89,1.56]	1.69	[1.29,2.20] *	1.16	[0.68,2.01]	2.14	[1.30,3.53] *
# of food outlets	1.02	[0.95,1.10]	0.73	[0.67,0.80] *	1.01	[0.89,1.16]	0.71	[0.60,0.82] *
Presence of fast food outlets	1.15	[0.65,2.04]	1.77	[0.92,3.42]	0.64	[0.27,1.50]	0.75	[0.31,1.80]
Day of week and measurement time period								
Measurement time period 2	0.75	[0.53,1.06]	0.77	[0.55,1.08]	0.54	[0.35,0.83] *	0.51	[0.34,0.79] *
Weekend day	0.87	[0.78,0.96] *	0.39	[0.35,0.44] *	0.97	[0.86,1.09]	0.62	[0.55,0.70] *

†Random intercept models account for clustering on each participant. Models adjusted for age, race (White, Hispanic, Other), free-and-reduced lunch eligibility, and the following home neighborhood characteristics: population density, jobs-housing ratio, road density, and % of households under the federal poverty line.

*denotes p-value <0.01; no coefficient had a p-value> 0.01 and <0.05.