Health & Place 18 (2012) 46–54

Contents lists available at SciVerse ScienceDirect

Health & Place

journal homepage: www.elsevier.com/locate/healthplace

A study of community design, greenness, and physical activity in children using satellite, GPS and accelerometer data

Estela Almanza [a,*], Michael Jerrett [a], Genevieve Dunton [b], Edmund Seto [a], Mary Ann Pentz [b]

[a] Division of Environmental Health Sciences, School of Public Health, University of California, Berkeley, Berkeley, CA 94720-7360, USA
[b] Department of Preventive Medicine, Keck School of Medicine, University of Southern California, Los Angeles, CA 90089-9031, USA

ARTICLE INFO

Article history:
Received 15 May 2011
Received in revised form
7 September 2011
Accepted 7 September 2011
Available online 16 September 2011

Keywords:
Physical activity
GPS
Greenspace
Built environment
Smart growth
Obesity

ABSTRACT

This study examined relationships between greenness exposure and free-living physical activity behavior of children in smart growth and conventionally designed communities. Normalized Difference Vegetation Index (NDVI) was used to quantify children's ($n=208$) greenness exposure at 30-s epoch accelerometer and GPS data points. A generalized linear mixed model with a kernel density smoothing term for addressing spatial autocorrelation was fit to analyze residential neighborhood activity data. Excluding activity at home and during school-hours, an epoch-level analysis found momentary greenness exposure was positively associated with the likelihood of contemporaneous moderate-to-vigorous physical activity (MVPA). This association was stronger for smart growth residents who experienced a 39% increase in odds of MVPA for a 10th to 90th percentile increase in exposure to greenness (OR=1.39, 95% CI 1.36–1.44). An individual-level analysis found children who experienced >20 min of daily exposure to greener spaces (>90th percentile) engaged in nearly 5 times the daily rate of MVPA of children with nearly zero daily exposure to greener spaces (95% CI 3.09–7.20).

1. Introduction

The prevalence and amount of physical activity among adults and children in the United States and Europe is disturbingly low compared to levels recommended for maintaining good health (US Department of Health and Human Services, 1999; Martinez-Gonzalez et al., 2001; Macera et al., 2003; Caballero, 2007; Troiano et al., 2008). This deficiency is particularly serious for children because activity behavior and associated health effects that are formed early in life are likely to continue into adulthood (Freedman et al., 2005; Kjonniksen et al., 2008). Physical inactivity is linked to increased morbidity and premature mortality as it contributes to numerous chronic conditions including obesity, diabetes, hypertension, cardiovascular disease, certain cancers, depression, and osteoporosis (US Department of Health and Human Services, 2002).

Underlying causes for the lack of physical activity may include changes in urban structure and the built environment that reduce opportunities for physical activity (Brownson et al., 2005). Evidence points to a relationship between community design, active living, and health (Saelens et al., 2003; McCormack et al., 2004; Frank et al., 2005; Sallis et al., 2009). Design features that may shape activity behavior and health outcomes include land use mixture (Frank et al., 2006; Rodriguez et al., 2006; Troped et al., 2010), traffic density and safety (Foster et al., 2009; Jerrett et al., 2010), and access to green spaces and recreational resources (Sallis et al., 2000; Humpel et al., 2002; Davison and Lawson, 2006; Norman et al., 2006; Kaczynski and Henderson, 2007; Tilt et al., 2007; Witten et al., 2008; Dunton et al., 2009; Jones et al., 2009; Coombes et al., 2010; Quigg et al., 2010; Wolch et al., 2010).

One particular community design in the United States known as 'smart growth', has been hypothesized to promote active living. Smart growth is a set of principles for guiding development of healthy, vibrant communities characterized by a sense of place. Principles include mixed land use (e.g. residential, commercial, school), diverse housing and transportation options, connected, walkable streets, areas for social interaction (parks, community centers) and compact building design (Song, 2005; EPA, 2011; Smart Growth Online, 2011). In a recent review, Durand et al. (2011) found several smart growth design principles associated with physical activity.

Greenness is an aspect of community design related to several smart growth principles (walkability, mixed land use, sense of place). In the broadest sense, greenness describes level of vegetation, ranging from sparsely-landscaped streets to tree-lined walkways to playfields and forested parks. Possible mechanisms by which greenness may promote activity include programmed sports and informal play that occur in open green spaces.

* Corresponding author.
E-mail address: ealmanza@berkeley.edu (E. Almanza).

1353-8292
doi:10.1016/j.healthplace.2011.09.003

Shade and esthetics provided by tree-lined sidewalks may encourage walking and outdoor activities. Greenbelts provide connectivity for active transport or leisure walks. In a review conducted by Kaczynski and Henderson (2007), proximity to parks and trails was associated with increased activity. Wheeler et al. (2010) found that boys' activity levels in green areas were of higher intensity. Although evidence was mixed, Lachowycz and Jones (2011) reported 33 of 50 systematically reviewed studies demonstrated some evidence linking physical activity to residential green space accessibility. Links to other health outcomes such as weight status have also been drawn (Lee and Maheswaran, 2011). Children's neighborhood vegetation level, as measured by the Normalized Difference Vegetation Index (NDVI), has been found to be inversely associated with risk of overweight (Liu et al., 2007; Bell et al., 2008). In a longitudinal study conducted by Wolch et al. (2010), children were followed for 8 years and results indicated more park space within neighborhoods was associated with lower attained Body Mass Index (kg/m^2) at age 18.

As greenness contributes to multiple community design features, one could reasonably expect a synergistic relationship between greenness and other design features (e.g., recreation, shade, neighborhood attractiveness). For example, a tree-lined sidewalk may be more conducive to active transport than an unsheltered one. A basketball court near a grassy area with scattered shrubs and trees may be more inviting for a meeting of friends, which may lead to a spontaneous game of hide-and-seek or other unstructured play. On a larger scale, comprehensive community planning, such as smart growth, that integrates greenness with other design features may have greater social and health benefits. For example, an accessible green space with trails is more likely to encourage activity than one separated from homes by major roads. Research suggests well-connected communities with more useful green areas may be of greater value in promoting active living (Saelens et al., 2003; Giles-Corti et al., 2005; Rodriguez et al., 2005; Berrigan et al., 2010).

Despite the growing body of research supporting links between community design and built environment features and physical activity, the evidence base is mixed, and also limited because most studies have been based on self-report data (McCormack et al., 2004; Hillsdon et al., 2006; Ferreira et al., 2007; Maas et al., 2008; Coombes et al., 2010; Lachowycz and Jones, 2011). Self-report data limits inferences drawn about activity associations because perceptions about behavior and environmental context are susceptible to recall bias and misclassification error.

To address this limitation, in an ongoing study that takes place in the United States near Chino, California, called 'Healthy PLACES' (Promoting Livable Active Community EnvironmentS), portable global positioning system (GPS) and accelerometer units were used simultaneously to study the connection between community design features and physical activity behavior of families living either in a smart growth community or nearby conventional community. The continuous logging of time-location by GPS and physical activity by accelerometers provides an opportunity to objectively measure activity within environmental context, and may allow one to draw stronger links between behavioral patterns and contemporaneous exposure to spatial attributes such as greenness (Saelens et al., 2003; Rodriguez et al., 2005; Duncan et al., 2009; Jones et al., 2009; Maddison and Mhurchu, 2009; Cooper et al., 2010; Quigg et al., 2010; Troped et al., 2010; Wheeler et al., 2010). This study analyzed children's neighborhood activity data from Healthy PLACES to examine the association between greenness exposure and physical activity behavior, and whether this relationship was modified by community design. Two hypotheses were tested: (1) momentary (30-s epoch) greenness exposure was associated with the level of physical activity performed by children in that location; and (2) this association was stronger for smart growth residents.

2. Methods

2.1. Study design and participants

Healthy PLACES is a quasi-experimental intervention study examining multi-contextual, cross-sectional, and longitudinal effects of residing in a smart growth community on the prevention of obesity for families. The working hypothesis of Healthy PLACES is that residents of a smart growth community will demonstrate higher levels of physical activity and healthier lifestyle attitudes compared to residents from nearby low-density, conventional communities. The recruited intervention group consists of families who recently moved to The Preserve, a newly developed smart growth community in Chino, California. Families from six nearby communities (within 30 min drive of The Preserve) who considered moving into The Preserve were recruited as the comparison group and were matched on demographics and income. Participant families include one parent and one child of age 8–14 and are followed for four years. Institutional Review Boards at the University of Southern California and University of California Berkeley approved the study and written informed consent and minor assent were obtained from parents and children.

The current study was cross-sectional and included Healthy PLACES data collected March 2009–March 2010. The baseline sample included 386 children.

2.2. Measures

2.2.1. Demographic and anthropometric

Survey data included age, gender, ethnicity, annual household income, and home address. Missing income data were imputed with the median of the entire sample of 386 ($60,000). Height and weight were measured using a stadiometer (PE-AIM-101) and an electronically calibrated digital scale (Tanita WB-110A) to the nearest 0.1 cm and 0.1 kg, respectively. Body Mass Index (BMI) was calculated as kg/m^2.

2.2.2. Activity and location

Participants were provided with an Actigraph GT2M accelerometer (Actigraph LLC, FL, USA) for objective assessment of physical activity, and a BT-335 portable GPS (GlobalSat Technology Corp, Taiwan) to collect location information simultaneously. The accelerometers recorded date, time, activity counts and steps. The 16 M bit, 1575.42 MHz GPS units recorded date, time, latitude, longitude, altitude, and speed using datum World Geodetic Survey 1984 (up to 60,000 geo-locations). Wide Area Augmentation System (WAAS)/EGNOS/MSAS and a SiRF star III chipset improved tracking accuracy (5 m 2D RMS). Phone messages reminded participants to recharge units (battery life 25 h). Both devices were pre-set to record at 30-s intervals. They were attached to a belt and worn on the right hip continuously for 7 days except when sleeping, bathing, or swimming. Data collection will continue annually for each parent and child pair for 4 years.

2.2.3. Greenness exposure

To assess greenness objectively, the merged accelerometer-GPS data (30-s intervals) were overlaid on NDVI data in a geographical information system ArcGIS 9.3 (ESRI, Redlands, CA). NDVI was calculated from Landsat 5 Thematic Mapper satellite imagery available from the US Geological Survey at 30 m pixel resolution for the period March–May 2010. NDVI is an indicator for the amount of vegetation in each pixel (Cohen and Goward, 2004). The index ranges from -1 to $+1$ and higher values indicate more vegetation. Each location-activity point was assigned an NDVI value as a measure of greenness exposure. Negative values, generally representing water, ice, and bare earth, were coerced to zero. NDVI was subsequently re-scaled by dividing all values by the 10–90th percentile range. This facilitated interpretation of regression analysis coefficients since a one-unit change in NDVI, the predictor variable, would have been outside the range of observed data. With re-scaling, a one-unit change represents the difference between the 10th and the 90th percentile values.

2.3. Data merging and processing

Accelerometer and GPS data were merged and processed in R v2.9.2 (R Development Core Team). Records were matched by date and time to the nearest 30-s epoch. Recording intervals with >60 min of consecutive zero activity counts were classified as accelerometer non-wear (Troiano et al., 2008). Accelerometer activity count data were classified as MVPA using age-specific thresholds for predicted metabolic equivalents ≥ 4 derived from the Freedson equation (Freedson et al., 2005). Activity outliers were identified as records with $>16{,}383$ counts per 30-s. Records with speeds >169 kph (105 mph) were considered outliers because typical driving speeds are well below this value. Motorized activity was identified by speeds >32 kph (20 mph) since typical bicycling speeds range from 15 to 30 kph (9.32–18.64 mph).

To identify home and neighborhood points, children's home addresses were geocoded in ArcGIS. Since the geocoding road layer did not contain several new roads in the smart growth community, some addresses were geocoded manually using iTouchMap (iTouchMap.com) and validated with MapQuest and Google Maps. Activity data were identified as home points if they fell within the 30 m Euclidian distance buffer about the home. Points within 500 m of the home were identified as neighborhood points. A 500 m radius is often used to represent neighborhoods as it approximates a 10–15 min walk (Wolch et al., 2010).

2.4. Data analysis

2.4.1. Scope

The initial inclusion criterion was that children have ≥ 3 days with a minimum of 4 h of valid GPS-accelerometer data each, where valid data excluded missing, outlier, night (11pm–5am), and accelerometer non-wear data.

To investigate physical activity behavior of children within the neighborhood environment outside of home and school, the scope of the analysis was limited to neighborhood data and excluded home and motorized activity. Data recorded during school hours (9am-2pm weekdays, August 31-June 10) were removed (Chino Valley Unified School District, 2011). After removal of home, school-time, and motorized data, participants with <1 h of neighborhood data were excluded from analysis.

2.4.2. Analyses overview

The primary objective of this study was to explore whether momentary greenness exposure was associated with contemporaneous physical activity behavior. A spatially-explicit analysis at the 30-s time-location point scale was conducted. For comparison, the relationship between greenness exposure and daily amount of physical activity at the individual level was also examined.

2.4.3. Momentary analysis

Geovisualization of momentary (30-s epoch) data allowed exploration of neighborhood activity patterns. The effect of greenness on the within-person variation of physical activity was tested in a multilevel model clustered on the individual. The unit of analysis was the 30-s epoch. Logistic regression was applied to examine the association between momentary exposure to greenness (NDVI) and the odds of contemporaneous moderate-to-vigorous physical activity. A random effect on individual adjusted for repeated measures. To address potential non-independence among observations a spatial moving density term of MVPA was included. This term was a kernel density estimate of all individuals' instances of MVPA within 100 m interpolated to every observation in the analysis. The estimation procedure was analogous to a weighted moving average with a decay function that down-weights more distant observations (Bailey and Gatrell, 1995). Potential individual-level confounders included race, categorized into Caucasian/White, African American/Black, Hispanic, Asian, and other (other, mixed, bi-racial, Hawaiian/Pacific Islander, American Indian), age (8–10 and 11–14), gender, and annual household income. Individual BMI was included to adjust for potential differences in activity by body composition. A time-varying categorical variable representing three types of leisure time, "before and after school", "school weekends", and "summer", assessed temporal variation of activity. This variable also served to partially adjust for seasonal effects on activity behavior. To examine differences in behavior of children from smart growth versus conventionally designed low-density communities, a community design group variable was included and its interaction with greenness (NDVI) was tested to assess whether community design modifies the association between greenness and MVPA. Model selection was based on stepwise forward regression (p-value < 0.05).

Since observations closer in distance tend to be more similar, the presence of spatial autocorrelation, indicating non-independence among observations, was assessed. Empirical semi-variograms were inspected to assess the degree of correlation as a function of distance between observations (Bailey and Gatrell, 1995). A Moran's I was calculated in OpenGeoDa 0.9.9.8 based on a Thiessen polygon contiguity matrix with a Queen's case connectivity of order 4 to evaluate more formally model residual autocorrelation (GeoDa).

2.4.4. Individual-level analyses

For comparison, the relationship between greenness and physical activity was also assessed at the individual level. Two individual-level analyses examined whether children's amount of MVPA performed in their neighborhood was associated with their exposure to greenness within their neighborhoods. Both analyses fit a negative binomial generalized linear model in which the outcome was the average daily minutes of neighborhood-MVPA. For model 1, 30-s epochs were first classified as occurring in 'greener' spaces if their NDVI value was greater than the 90th percentile of all points included in the analysis. Epochs were then aggregated by individual to create a categorical greenness exposure variable that classified children as having experienced an average of nearly zero, 1.5–20, or >20 min of daily exposure to greener spaces within the neighborhood. In model 2, greenness exposure assessment was coarser as it was not based on GPS data but on the mean NDVI value for the neighborhood (500 m buffer around homes). Both analyses were conducted on the same dataset as the momentary analysis and controlled for gender, age, income, and race. Other covariates included BMI, community design group, and the interaction between community design and the greenness variables.

3. Results

3.1. Descriptive statistics

Of the 386 children at baseline, 178 (Table 1 footnote) did not meet inclusion criteria for the neighborhood analysis, reducing the final sample to 208. Sixty-five were from the smart growth intervention group and 143 were from the comparison group, residents of nearby conventional communities. The smart growth group had a higher median annual income, larger percentage of Asians, and smaller percentage of Hispanics than the comparison group (Table 1). Both groups had similar gender, age, and BMI distributions. Kruskal–Wallis and ANOVA tests found demographics of the final sample were similar to those of participants excluded from analysis.

After removal of outlier, missing, accelerometer non-wear, motorized, night, and school-time data, the median value for a child's average daily minutes recorded time in the neighborhood was greater for the smart growth group (51.64) than the conventional group (31.86) (Table 1). Median values for a subject's average daily minutes of neighborhood-MVPA were 7.50 and 4.25 for the smart growth and conventional groups, respectively (p-value = 0.05). The smart growth group had a higher median value for neighborhood average NDVI (Table 1).

Accelerometer and GPS summary statistics in Table 2 illustrate smart growth residents had greater percentages of missing GPS data than the conventional group.

3.2. Momentary analysis

Exposure to greenness was significantly associated with the probability of MVPA at the momentary 30-s epoch scale (Table 3). This was consistent with geovisualization suggesting MVPA often occurred in proximity to green areas (Fig. 1). The interaction between NDVI and community design group was significant (p-value < 0.05), producing an odds ratio of MVPA that was slightly higher for smart growth (OR = 1.39, 95% CI 1.36–1.44) compared to conventional community residents (OR = 1.34, 95% CI 1.30–1.38). For smart growth residents, a momentary exposure to a higher level of greenness (an NDVI increment of 0.11, which was equivalent to the difference between the 10th and 90th percentile values) was associated with a 39% increase in odds of MVPA compared to a 34% increase in odds for conventional community residents.

Table 3 shows that on average, girls were less likely to engage in MVPA than boys. There was no evidence of association between the likelihood of MVPA and age, race, income or community design group. The probability of MVPA was not associated with BMI (p-value = 0.28). Children were less likely to perform MVPA during school-season weekends compared to before- and after-school on weekdays. The likelihood of MVPA during summer-season days was no different from school-season before- and after-school weekdays.

Empirical semi-variograms suggested observations were spatially autocorrelated up to a range of 100 m. Hence, a 100 m MVPA kernel density term was included in the model. Inclusion of this term negligibly affected parameter and standard error estimates. A Moran's I test of autocorrelation on the final model residuals rejected the null hypothesis (p-value < 0.001) but the magnitude of the Moran's I was small (0.09) indicating that although significant, the effect of remaining autocorrelation on the estimation was likely minimal.

Table 1
Demographic, activity, and neighborhood greenness characteristics of the 208 participants included in the analysis by community design group[a].

	Conventional (n = 143)	**Smart growth** (n = 65)	***p*-value**[b]
Gender: n (%)			
Male	70 (48.95)	30 (46.15)	0.71
Female	73 (51.05)	35 (53.85)	
Age: n (%)			
8–10 years	53 (37.06)	26 (40.00)	0.69
11–14 years	90 (62.94)	39 (60.00)	
BMI: (kg/m2)			
Median (range)	19 (13–39)	19 (13–33)	0.20
Race: n (%)			
Caucasian	37 (25.87)	18 (27.69)	0.78
African American	3 (2.10)	5 (7.69)	0.05
Hispanic	68 (47.55)	19 (29.23)	0.01
Asian	8 (5.60)	14 (21.54)	< 0.01
Other (mixed, other, Haw/PI, Am. Ind)	27 (18.88)	9 (13.85)	0.38
Annual household income[c]: ($1000s)			
Median (range)	48 (5–160)	80 (5–160)	< 0.001
Neighborhood average daily minutes [d]			
Median (range)	31.86 (7.93–438.57)	51.64 (10.25–220.67)	0.01
Neighborhood-MVPA average daily minutes [d]			
Median (range)	4.25 (0–47.67)	7.50 (0–36.50)	0.05
Neighborhood average NDVI [e]			
Median (range)	0.05 (0–0.68)	0.10 (0–0.74)	< 0.001

[a] 178 participants did not meet inclusion criteria. Twenty-five participants were missing their GPS or accelerometer file. Thirty-four did not meet the initial minimum valid days criterion. Sixty had < 1 h of neighborhood points. Fifty-nine did not have data reflecting their geocoded address.

[b] ANOVA and Kruskal–Wallis tests applied for assessing differences between groups.

[c] US Dollars.

[d] Calculated after excluding missing, outlier, accelerometer non-wear, motorized, night, and school data.

[e] Derived from LANDSAT imagery. NDVI is calculated as the relative reflectance of radiation from near infrared to visible red spectra (NIR-Red/NIR + Red) and is an indicator of vegetation as growing plants reflect near-infrared and absorb radiation in the visible range. Negative 30 m × 30 m pixel values primarily representing water were reassigned to 0, then mean NDVI was calculated for all 30 m × 30 m pixels within 500 m buffers around geocoded residential addresses. For the regression model neighborhood mean NDVI values were rescaled by dividing by the 10–90th percentile range of these values.

Table 2
Accelerometer and GPS sampling characteristics of the 208 participants included in the analysis by community design group[a].

	Conventional (n=143) mean (range)	**Smart Growth** (n=65) mean (range)	***p*-value**[b]
Number of days	7.90 (6.00–8.00)	7.90 (7.00–8.00)	0.26
% Missing accelerometer data[c]	0.91 (0–24.20)	1.46 (0–21.01)	0.01
% Missing GPS data	29.93 (2.51–77.54)	39.90 (7.52–76.60)	< 0.001
% Accelerometer outliers[d]	< 0.01 (0–0.03)	0.29 (0–18.73)	0.80
% GPS outliers[e]	< 0.01 (0–0.000084)	< 0.01 (0–0.000081)	0.79
% Accelerometer non-wear[f]	38.02 (18.20–75.54)	37.43 (6.92–64.00)	0.73
% Motorized[g]	1.96 (0–5.53)	2.34 (0.03–4.86)	0.04

[a] Summary statistics describe data collected between 5am–11pm, excluding school hours on weekdays 9am–2pm during the school season August 31–June 10.
[b] ANOVA and Kruskal–Wallis tests applied for assessing differences between groups.
[c] The mean values in this table represent the means for "% of 30-s epochs for each participant".
[d] Accelerometer records with greater than 16,383 counts per 30-s epoch.
[e] GPS records with speeds greater than 169 kph (105 mph).
[f] Accelerometer records comprising at least 60 min of consecutive zero activity counts.
[g] GPS records with speeds greater than 32 kph (20 mph).

Table 3
The association between momentary greenness exposure and the odds of MVPA at 30-s interval point locations. The analysis was restricted to residential neighborhood activity and the logistic model included a random effect on individual to account for nested measures[a].

	Definition	**β (95% CI)**	**OR (95% CI)**	***p*-value**
Response variable				
MVPA	0: Sedentary/light			
	1: Moderate/vigorous			
Covariates				
NDVI[b]	Normalized difference vegetation index	0.29 (0.27, 0.32)	1.34 (1.30, 1.38)	< 0.001
Community	0: Conventional			
	1: Smart growth	0.23 (− 0.20, 0.65)	1.26 (0.82, 1.92)	0.29
Gender	0: Male			
	1: Female	− 0.50 (− 0.85, − 0.14)	0.61 (0.43, 0.87)	0.01
Age	0: 8–10 years			
	1: 11–14 years	− 0.37 (− 0.76, 0.02)	0.69 (0.47, 1.02)	0.06
Income	Annual income ($1000 US dollars)	− 0.005 (− 0.009, 0)	0.995 (0.991, 1.000)	0.06
Race	Reference: Caucasian			
African American		− 0.21 (− 1.20, 0.78)	0.81 (0.30, 2.18)	0.67
Hispanic		− 0.05 (− 0.51, 0.41)	0.95 (0.60, 1.50)	0.82
Asian		− 0.33 (− 0.97, 0.32)	0.72 (0.38, 1.38)	0.33
Other[c]		− 0.37 (− 0.93, 0.18)	0.69 (0.40, 1.20)	0.19
Leisure	Reference:			
School weekends	Before and after school until 2300 h	− 0.47 (− 0.52, − 0.41)	0.63 (0.59, 0.66)	< 0.001
Summer	on school-season weekdays	− 0.19 (− 0.60, 0.23)	0.83 (0.55, 1.26)	0.38
MVPA kernel[d]		− 16.85 (− 26.17, − 7.53)		< 0.001
NDVI × Community	Interaction	0.04 (0.001, 0.085)	1.044 (1.001, 1.089)	0.04

[a] There was a total of 142,552 30-s epochs for 208 participants. The epoch was the unit of analysis.
[b] Negative NDVI values primarily representing water were assigned 0. For regression all values were rescaled by dividing by their 10–90th percentile range.
[c] Race category "other" includes mixed, other, Hawaiian/Pacific Islander, and American Indian.
[d] MVPA kernel density estimate (bandwidth 100 m) included to address spatial autocorrelation.

3.3. *Individual-level analyses*

Two individual-level analyses were conducted examining the association between mean daily minutes of MVPA performed in the neighborhood and two different neighborhood greenness exposure predictors (Table 4). While controlling for potential confounders gender, age, income, and race, model 1 results suggest that for neighborhood activity children who experienced 1.5–20 min of daily exposure to greener spaces (> 90th percentile) engaged in 2.11 times the daily rate of MVPA of children with nearly zero daily exposure to greener spaces. Children who experienced > 20 min of daily exposure to greener spaces engaged in 4.72 times the daily rate of MVPA of children with nearly zero daily exposure to greener spaces. This relationship exhibited a linear trend (p-value < 0.001). The median values for average daily neighborhood-MVPA were 2.9, 7.6, and 14.6 min for children who experienced neighborhood exposure to greener spaces of nearly zero, 1.5–20, and > 20 min daily, respectively. Approximately 50% of children had nearly zero daily exposure to greener spaces within the neighborhood. In model 2 the coarser greenness exposure predictor, mean neighborhood NDVI, was not associated with daily neighborhood-MVPA.

Race was not significant in either model. Gender was consistently significant with coefficient approximately -0.46 (p-value < 0.01), indicating boys engaged in 1.58 times the daily rate of neighborhood-MVPA of girls. The coefficient for age (0: 8–10, 1: 11–14) was -0.33 and only significant in model 2 (p-value $= 0.03$). Income (thousands US dollars) coefficient, -0.01, was only significant in model 1 (p-value < 0.05). BMI, community design, and the community design interaction with the greenness variables were never significant.

4. Discussion and conclusions

Novel exposure assessment methods were used to test whether momentary greenness exposure was associated with the likelihood of MVPA for children residing in smart growth and conventionally designed communities. The analysis was limited to neighborhood activity outside of homes during non-school hours. For children ages 8–14, momentary greenness was positively associated with physical activity while controlling for individual confounders and a spatial moving density of MVPA. Results at the 30-s epoch scale suggest a 34–39% increase in odds of MVPA for a 10th to 90th percentile increase in exposure to greenness quantified by an NDVI increase of 0.11. In the typical neighborhood settings assessed in this dataset, this incremental change in greenness usually corresponded to the difference between a mostly paved area and mostly grass or shrub covered area.

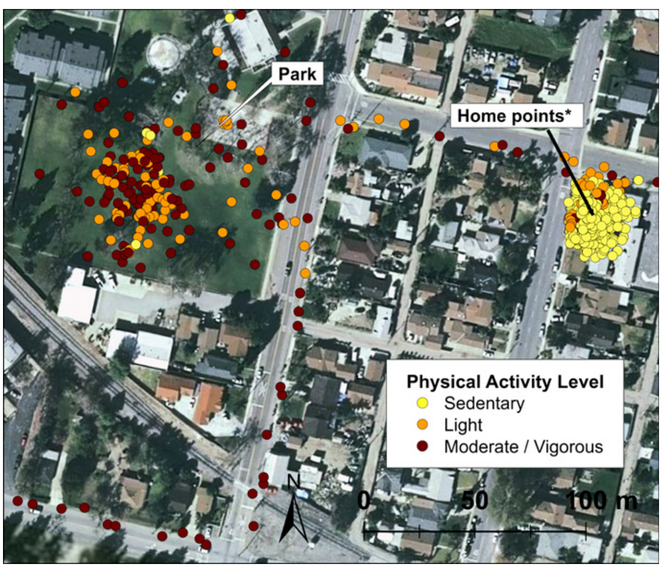

Fig. 1. Geovisualization of a child's personal monitoring points show MVPA occurring within green areas and during active transport (* home points shifted for confidentiality).

This is one of the first studies to use objective measures to examine the contemporaneous association between greenness and free-living activity of children, and the first to assess the effect modification by community design in a quasi-experimental setting. Study findings were consistent with Jones et al. (2009) who found common locations for children's physical activity included gardens and green spaces. However, these authors analyzed aggregated GPS-accelerometer data (MVPA bouts > 5 -min) and green spaces were classified by land use type (e.g. gardens, parks, grassland). The current results were also consistent with Wheeler et al. (2010) who found a 37% increase in odds of MVPA (OR = 1.37) for epochs occurring in green spaces for 10–11 yr-old boys. These authors also used GPS, accelerometer, and land use data. The variation in how greenness is quantified and defined presents challenges for comparing results across studies. Some researchers quantify proximity to or availability of specified green land uses (Roemmich et al., 2006; Maas et al., 2008) whereas greenness exposure was quantified in the current study indiscriminate of land use.

The association reported between momentary greenness and physical activity was slightly stronger for children living in the smart growth community compared to nearby conventional low-density communities. This finding supports the hypothesis that well-designed communities may provide more useful green spaces. Indeed there may be multiple important interactions between greenness and other design features, namely walkability, esthetics, safety, and mixed land uses. Geovisual inspection of the data suggests a fair amount of green-MVPA may have occurred during active transport to/from school. Analysis of the leisure-time variable found children more likely to engage in neighborhood-MVPA before and after-school compared to weekends

Table 4
Individual-level analyses of mean daily minutes of MVPA performed in the neighborhood in relation to two different greenness exposure predictors. The negative binomial generalized linear models controlled for gender, age, income and race. Other covariates tested were BMI, community, and the interaction between community and greenness variables.

Model[a,b]	β (95% CI)	Exp(β) (95% CI) multiplicative effect on daily min MVPA	*p*-value
Response variable: MVPA time			
Mean daily minutes of neighborhood-MVPA			
Negative binomial regression with a log link			
Predictor model 1: exposure to greener spaces[c]			
0: near zero average daily exposure (Ref.)			
1: 1.5–20 min average daily exposure	0.75 (0.47, 1.02)	2.11 (1.60, 2.77)	< 0.001
2: > 20 min average daily exposure	1.55 (1.13, 1.97)	4.72 (3.09, 7.20)	< 0.001
Predictor model 2: neighborhood greenness			
Mean neighborhood NDVI[d]	0.13 (−0.27, 0.53)	1.14 (0.77, 1.70)	0.51

[a] $n = 208$ participants.
[b] Gender significant in both models. Income significant in model 1. Age significant in model 2. Race, BMI, the community design variable, and the community design interaction with the greenness variables were not significant in either model.
[c] 30-s epochs with NDVI > 90th percentile of dataset values were classified as a "greener space".
[d] Negative NDVI 30 m × 30 m pixel values primarily representing water were assigned 0. Mean NDVI was calculated for all 30 m × 30 m pixels within 500 m buffers around geocoded residences. For the regression neighborhood mean NDVI values were rescaled by dividing by their 10–90th percentile range.

during the school-season (p-value < 0.001). This was consistent with previous research demonstrating after-school time spent outdoors is an important source of physical activity (Cleland et al., 2008; Cooper et al., 2010). A centrally located school in the smart growth community may have promoted active transport, exposure to greener spaces, opportunities for unstructured play, and increased MVPA.

4.1. Strengths

A strength of the current study was the use of novel exposure assessment methods to investigate micro-geographic associations between momentary (30-s) greenness and physical activity. The momentary analysis approach provided information on conditions wherein MVPA occurs, thus allowing stronger inference about the environmental context of activity. In comparison, the two individual-level analyses highlighted the value of a momentary approach. In contrast to the momentary analysis, neither individual-level model found an interaction between greenness and community design. Furthermore, these models did not explicitly link greenness exposure to contemporaneous instances of MVPA. Rather, they examined daily average neighborhood-MVPA as a function of two spatially-implicit neighborhood exposure variables. It is of note that the coarser of the two exposure variables (model 2), mean neighborhood NDVI, was not associated with neighborhood-MVPA. Conversely, the greenness exposure variable based on aggregation of momentary GPS data (model 1) produced results that mirrored the spatially-explicit momentary analysis. Specifically, individual-level model 1 suggests children who experienced >20 min of daily exposure to greener spaces within neighborhoods engaged in almost 5 times the daily rate of neighborhood-MVPA of children with nearly zero daily exposure to greener spaces. These findings suggest an increase in power to detect associations with spatially-explicit analyses.

The analytical sample ($n=208$) represented a wide range of ages, income levels, and a substantial proportion of ethnic minorities (42% Hispanic). This was particularly important for working towards understanding activity behavior of low-income minorities who are especially vulnerable to obesity (Cohen et al., 2007). Additionally, sampling captured all waking hours weekdays and weekends during summer and school-year months, which allowed assessment of temporal variation of behavior. Furthermore, the study's quasi-experimental design mitigated self-selection bias since the demographically-matched comparison group recruited from nearby communities consisted of families who considered moving into the newly developed smart growth intervention community.

Finally, the study addressed potential spatial autocorrelation among observations by inclusion of the MVPA kernel density estimate in the model. Although more refined methods are warranted in the future, the authors are unaware of similar attempts to incorporate spatial terms into models exploring relationships between the environment and activity using GPS and accelerometer data.

4.2. Limitations

Several study limitations are noted. First, negative NDVI values representing water or bare earth were set to zero, but clouds may also register negative values potentially misclassifying land below clouds. The satellite imagery used, however, had less than 6% cloud cover and these clouds were primarily outside the spatial extent of participant residential communities. Another potential source of bias was that the imagery was obtained for March–May of 2010; whereas space-time-activity data was collected between March 2009 and March 2010. Seasonal differences between imagery and data-collection periods may have led to greenness exposure misclassification especially in relation to the phenology of large shade trees and landscaping within communities. Additionally, analyses did not assess how weather and amount of daylight affected children's activity. The inclusion of the leisure-time variable, however, partially addressed seasonality factors since one of the categories represented summer months. Furthermore, the data-collection protocol excluded late-July, August, and January to offset extreme weather effects.

GPS measurement error made it especially difficult to distinguish children's home points (within 30 m buffer). Geovisualization indicated buffers likely captured yard, street, and neighboring home activity, thereby excluding such activity from analysis. This misclassification was unlikely to bias results because of the focus on more common spaces (e.g., parks, walkways) within neighborhoods. A further limitation on the use of accelerometers was their insensitivity to bicycling activity. This problem was unlikely to bias results because cycling occurred infrequently within this population. Moreover, non-wear time for particular activities (e.g. sports, swimming) may have under-represented environments supportive of these activities.

The loss of GPS signal reduced the amount of useable accelerometer data for spatial analyses. To maximize data retention for analysis, instead of using standard accelerometer cut-offs of 8–10 h, a valid day consisted of ≥ 4 h of valid GPS-accelerometer data and inclusion criteria required a minimum of 3 valid days. Thus far, researchers have used various GPS analysis criteria. To define a valid GPS day Troped et al. (2010) used a cut-off of 1 standard deviation below the mean of recorded daily data (40 min), while Cooper et al. (2010) included children with ≥ 3 h of outdoors GPS-accelerometer data on ≥ 1 day. Standardization of inclusion criteria for GPS-accelerometer studies is warranted.

The current study focused on neighborhood activity outside of homes and school-hours in suburban settings. As such, results are not generalizable to rural settings or behavior outside neighborhoods, inside homes, or during school-hours. Additionally, restricting the analyses excluded 119 participants because of insufficient neighborhood data. Analyses with the excluded data (e.g. inside homes, outside neighborhoods) would improve understanding of children's overall activity behavior.

Lastly, the use of NDVI for greenness exposure was a strength in that it captured most green features in the environment and was not limited to pre-classified green spaces, which may fail to include small or non-standard green areas. The current analysis was limited, however, as it did not assess the type of greenness feature (e.g. open, tree-lined walkway, recreational area, garden), accessibility, safety, frequency of organized sports at open green spaces, or whether some spaces promoted higher levels of activity due to quality or esthetics (Humpel et al., 2002; Bedimo-Rung et al., 2005; Giles-Corti et al., 2005; Hoehner et al., 2005; Hillsdon et al., 2006; Mitchell and Popham, 2007; Lee and Maheswaran, 2011). In particular, features of parks and public open spaces that may be important determinants of use for physical activity include trees, playgrounds, recreational facilities, drinking fountains, toilets, walking trails, and water features such as a pond (Giles-Corti et al., 2005; Kaczynski et al., 2008; Potwarka et al., 2008; Veitch et al., 2011). Furthermore, research has found that parks with age-appropriate playgrounds, trees, birds, walking paths, and basketball courts are significantly associated with greater physical activity among children and youth (Cohen et al., 2006; Timperio et al., 2008). These findings highlight the need of future research to look closer at specific features and qualitative differences of green areas while using objective measurement tools. In future studies, the authors will integrate current objective data with other GIS layers (e.g. park) as well as environment and recreational programming information from field audits (Day et al., 2006; Wolch et al., 2010) to tease out which features and types of green areas are most associated with physical activity of children in the Healthy PLACES study.

4.3. Conclusions

Results from momentary epoch-level and aggregated individual-level analyses indicate greenness is positively associated with children's physical activity. Although these results suggested modest effect sizes, the health impacts could be cumulatively substantial at the population-level. Additionally, the current finding that the greenness association was stronger for smart growth residents suggests future research should explore further whether community design moderates individuals' use of green spaces. In particular, the authors plan to examine how other smart growth elements interact with greenness to increase the likelihood of MVPA.

The current study extends the knowledge base with objective measures of greenness, time-location, and free-living activity of children. It also takes a step toward addressing spatial dependence among observations, which has relevance to other studies that attempt to draw inference from large personal monitoring datasets. Finally, if a greenness-physical activity effect is demonstrated longitudinally over the course of the Healthy PLACES study and it is linked to other health outcomes, this would provide an even stronger justification for integrating green spaces into community planning to promote health.

Acknowledgments

Funding for this project was provided by the National Cancer Institute grant #R01-CA-123243 (Pentz, PI), the UC Berkeley Chancellor's Fellowship, and the CDC-ASPH Environmental Health Scholarship. We acknowledge the Active Living Research Accelerometer Loan Program, Keito Kawabata, Robert Gomez and the entire Healthy PLACES research team at University of Southern California, and the Jerrett Lab at UC Berkeley. We are particularly grateful to Russ Landers, Brett Furnas, and Jason Su for their research assistance.

References

Bailey, T., Gatrell, T., 1995. Interactive Spatial Data Analysis. John Wiley & Sons, New York.
Bedimo-Rung, A.L., Mowen, A.J., Cohen, D.A., 2005. The significance of parks to physical activity and public health—a conceptual model. American Journal of Preventive Medicine 28, 159–168.
Bell, J.F., Wilson, J.S., Liu, G.C., 2008. Neighborhood greenness and 2-year changes in Body Mass Index of children and youth. American Journal of Preventive Medicine 35, 547–553.
Berrigan, D., Pickle, L.W., Dill, J., 2010. Associations between street connectivity and active transportation. International Journal of Health Geographics 9, 18.
Brownson, R.C., Boehmer, T.K., Luke, D.A., 2005. Declining rates of physical activity in the United States: what are the contributors? Annual Review of Public Health 26, 421–443.
Caballero, B., 2007. The global epidemic of obesity: an overview. Epidemiologic Reviews 29, 1–5.
Chino Valley Unified School District, 2011. 〈http://www.chino.k12.ca.us/〉 (accessed 27 January 2011).
Cleland, V., Crawford, D., Baur, L.A., Hume, C., Timperio, A., Salmon, J., 2008. A prospective examination of children's time spent outdoors, objectively measured physical activity and overweight. International Journal of Obesity 32, 1685–1693.
Cohen, W.B., Goward, S.N., 2004. Landsat's role in ecological applications of remote sensing. Bioscience 54, 535–545.
Cohen, D.A., Ashwood, J.S., Scott, M.M., Overton, A., Evenson, K.R., Staten, L.K., Porter, D., Mckenzie, T.L., Catellier, D., 2006. Public parks and physical activity among adolescent girls. Pediatrics 118, E1381–E1389.
Cohen, D.A., Mckenzie, T.L., Sehgal, A., Williamson, S., Golinelli, D., Lurie, N., 2007. Contribution of public parks to physical activity. American Journal of Public Health 97, 509–514.
Coombes, E., Jones, A.P., Hillsdon, M., 2010. The relationship of physical activity and overweight to objectively measured green space accessibility and use. Social Science & Medicine 70, 816–822.
Cooper, A.R., Page, A.S., Wheeler, B.W., Hillsdon, M., Griew, P., Jago, R., 2010. Patterns of GPS measured time outdoors after school and objective physical activity in English children: the PEACH project. International Journal of Behavioral Nutrition and Physical Activity 7, 9.
Davison, K., Lawson, C., 2006. Do attributes in the physical environment influence children's physical activity? A review of the literature. International Journal of Behavioral Nutrition and Physical Activity 3, 19.
Day, K., Boarnet, M., Alfonzo, M., Forsyth, A., 2006. The Irvine-Minnesota inventory to measure built environments: development. American Journal of Preventive Medicine 30, 144–152.
Duncan, M.J., Badland, H.M., Mummery, W.K., 2009. Applying GPS to enhance understanding of transport-related physical activity. Journal of Science and Medicine in Sport 12, 549–556.
Dunton, G.F., Kaplan, J., Wolch, J., Jerrett, M., Reynolds, K.D., 2009. Physical environmental correlates of childhood obesity: a systematic review. Obesity Reviews 10, 393–402.
Durand, C.P., Andalib, M., Dunton, G.F., Wolch, J., Pentz, M.A., 2011. A systematic review of built environment factors related to physical activity and obesity risk: implications for smart growth urban planning. Obesity Reviews 12, 1–10.
EPA, 2011. US Environmental Protection Agency, Smart Growth. 〈http://www.epa.gov/smartgrowth/index.htm〉 (accessed on 2 May 2011).
ESRI, Environmental Systems Research Institute, 2010. Redlands, California.
Ferreira, I., Van Der Horst, K., Wendel-Vos, W., Kremers, S., Van Lenthe, F.J., Brug, J., 2007. Environmental correlates of physical activity in youth—a review and update. Obesity Reviews 8, 129–154.
Foster, C., Hillsdon, M., Jones, A., Grundy, C., Wilkinson, P., White, M., Sheehan, B., Wareham, N., Thorogood, M., 2009. Objective measures of the environment and physical activity-results of the environment and physical activity study in English adults. Journal of Physical Activity & Health 6, S70–S80.
Frank, L.D., Sallis, J.F., Conway, T.L., Chapman, J.E., Saelens, B.E., Bachman, W., 2006. Many pathways from land use to health—associations between neighborhood walkability and active transportation, body mass index, and air quality. Journal of the American Planning Association 72, 75–87.
Frank, L.D., Schmid, T.L., Sallis, J.F., Chapman, J., Saelens, B.E., 2005. Linking objectively measured physical activity with objectively measured urban form: findings from SMARTRAQ. American Journal of Preventive Medicine 28, 117–125.
Freedman, D.S., Khan, L.K., Serdula, M.K., Dietz, W.H., Srinivasan, S.R., Berenson, G.S., 2005. The relation of childhood BMI to adult adiposity: the Bogalusa heart study. Pediatrics 115, 22–27.
Freedson, P., Pober, D., Janz, K.F., 2005. Calibration of accelerometer output for children. Medicine and Science in Sports and Exercise 37, S523–S530.
GeoDa. GeoDa Center for Geospatial Analysis and Computation. 〈http://geodacenter.asu.edu/〉.
Giles-Corti, B., Broomhall, M.H., Knuiman, M., Collins, C., Douglas, K., Ng, K., Lange, A., Donovan, R.J., 2005. Increasing walking: how important is distance to, attractiveness, and size of public open space? American Journal of Preventive Medicine 28, 169–176.
Martinez-Gonzalez, M.A., Varo, J.J., Santos, J.L., De Irala, J., Gibney, M., Kearney, J., Martinez, J.A., 2001. Prevalence of physical activity during leisure time in the European Union. Medicine and Science in Sports and Exercise 33, 1142–1146.
Hillsdon, M., Panter, J., Foster, C., Jones, A., 2006. The relationship between access and quality of urban green space with population physical activity. Public Health 120, 1127–1132.
Hoehner, C.M., Ramirez, L.K.B., Elliott, M.B., Handy, S.L., Brownson, R.C., 2005. Perceived and objective environmental measures and physical activity among urban adults. American Journal of Preventive Medicine 28, 105–116.
Humpel, N., Owen, N., Leslie, E., 2002. Environmental factors associated with adults' participation in physical activity: a review. American Journal of Preventive Medicine 22, 188–199.
itouchmap.Com. Mobile and Desktop Maps. 〈http://itouchmap.com/latlong.html〉.
Jerrett, M., Mcconnell, R., Chang, C.C.R., Wolch, J., Reynolds, K., Lurmann, F., Gilliland, F., Berhane, K., 2010. Automobile traffic around the home and attained body mass index: a longitudinal cohort study of children aged 10–18 years. Preventive Medicine 50, S50–S58.
Jones, A.P., Coombes, E.G., Griffin, S.J., Van Sluijs, E.M.F., 2009. Environmental supportiveness for physical activity in English schoolchildren: a study using Global Positioning Systems. International Journal of Behavioral Nutrition and Physical Activity 6, 8.
Kaczynski, A.T., Henderson, K.A., 2007. Environmental correlates of physical activity: a review of evidence about parks and recreation. Leisure Sciences: An Interdisciplinary Journal 29, 315–354.
Kaczynski, A.T., Potwarka, L.R., Saelens, B.E., 2008. Association of park size, distance, and features with physical activity in neighborhood parks. American Journal of Public Health 98, 1451–1456.
Kjonniksen, L., Torsheim, T., Wold, B., 2008. Tracking of leisure-time physical activity during adolescence and young adulthood: a 10-year longitudinal study. International Journal of Behavioral Nutrition and Physical Activity 5, 11.
Lachowycz, K., Jones, A.P., 2011. Greenspace and obesity: a systematic review of the evidence. Obesity Reviews 12, e183–e189.

Lee, A.C.K., Maheswaran, R., 2011. The health benefits of urban green spaces: a review of the evidence. Journal of Public Health 33, 212–222.
Liu, G.C., Wilson, J.S., Qi, R., Ying, J., 2007. Green neighborhoods, food retail and childhood overweight: differences by population density. American Journal of Health Promotion 21, 317–325.
Maas, J., Verheij, R., Spreeuwenberg, P., Groenewegen, P., 2008. Physical activity as a possible mechanism behind the relationship between green space and health: a multilevel analysis. BMC Public Health 8, 206.
Macera, C.A., Jones, D.A., Yore, M.M., Ham, S.A., Kohl, H.W., Kimsey Jr., C.D., Buchner, D., 2003. Prevalence of physical activity, including lifestyle activities among adults—United States, 2000–2001. Morbidity and Mortality Weekly Report 52, 766–769.
Maddison, R., Mhurchu, C.N., 2009. Global positioning system: a new opportunity in physical activity measurement. International Journal of Behavioral Nutrition and Physical Activity 6.
McCormack, G., Giles-Corti, B., Lange, A., Smith, T., Martin, K., Pikora, T.J., 2004. An update of recent evidence of the relationship between objective and self-report measures of the physical environment and physical activity behaviours. Journal of Science and Medicine in Sport 7, 81–92.
Mitchell, R., Popham, F., 2007. Greenspace, urbanity and health: relationships in England. Journal of Epidemiology and Community Health 61, 681–683.
Norman, G.J., Nutter, S.K., Ryan, S., Sallis, J.F., Calfas, K.J., Patrick, K., 2006. Community design and access to recreational facilities as correlates of adolescent physical activity and body-mass index. Journal of Physical Activity and Health 3 (1S1), 118–128.
Potwarka, L.R., Kaczynski, A.T., Flack, A.L., 2008. Places to play: association of park space and facilities with healthy weight status among children. Journal of Community Health 33, 344–350.
Quigg, R., Gray, A., Reeder, A.I., Holt, A., Waters, D.L., 2010. Using accelerometers and GPS units to identify the proportion of daily physical activity located in parks with playgrounds in New Zealand children. Preventive Medicine 50, 235–240.
R, R Development Core Team. 〈http://www.R-project.org〉.
Rodriguez, D.A., Brown, A.L., Troped, P.J., 2005. Portable global positioning units to complement accelerometry-based physical activity monitors. Medicine and Science in Sports and Exercise 37, S572–S581.
Rodriguez, D.A., Khattak, A.J., Evenson, K.R., 2006. Can new urbanism encourage physical activity? Comparing a new urbanist neighborhood with conventional suburbs. Journal of the American Planning Association 72, 43–54.
Roemmich, J.N., Epstein, L.H., Raja, S., Yin, L., Robinson, J., Winiewicz, D., 2006. Association of access to parks and recreational facilities with the physical activity of young children. Preventive Medicine 43, 437–441.
Saelens, B.E., Sallis, J.F., Black, J.B., Chen, D., 2003. Neighborhood-based differences in physical activity: an environment scale evaluation. American Journal of Public Health 93, 1552–1558.
Sallis, J.F., Bowles, H.R., Bauman, A., Ainsworth, B.E., Bull, F.C., Craig, C.L., Sjöström, M., De Bourdeaudhuij, I., Lefevre, J., Matsudo, V., Matsudo, S., Macfarlane, D.J., Gomez, L.F., Inoue, S., Murase, N., Volbekiene, V., Mclean, G., Carr, H., Heggebo, L.K., Tomten, H., Bergman, P., 2009. Neighborhood environments and physical activity among adults in 11 countries. American Journal of Preventive Medicine 36, 484–490.
Sallis, J.F., Prochaska, J.J., Taylor, W.C., 2000. A review of correlates of physical activity of children and adolescents. Medicine and Science in Sports and Exercise 32, 963–975.
Song, Y., 2005. Smart growth and urban development pattern: a comparative study. International Regional Science Review 28, 239–265.
Smart Growth Online. 〈http://www.smartgrowth.org/network.php〉 (accessed on 2 May 2011).
Tilt, J.H., Unfried, T.M., Roca, B., 2007. Using objective and subjective measures of neighborhood greenness and accessible destinations for understanding walking trips and BMI in Seattle, Washington. American Journal of Health Promotion 21, 371–379.
Timperio, A., Giles-Corti, B., Crawford, D., Andrianopoulos, N., Ball, K., Salmon, J., Hume, C., 2008. Features of public open spaces and physical activity among children: findings from the CLAN study. Preventive Medicine 47, 514–518.
Troiano, R.P., Berrigan, D., Dodd, K.W., Masse, L.C., Tilert, T., Mcdowell, M., 2008. Physical activity in the United States measured by accelerometer. Medicine and Science in Sports and Exercise 40, 181–188.
Troped, P.J., Wilson, J.S., Matthews, C.E., Cromley, E.K., Melly, S.J., 2010. The built environment and location-based physical activity. American Journal of Preventive Medicine 38, 429–438.
US Department of Health and Human Services, 1999. Physical Activity and Health. A Report of the Surgeon General Executive Summary. US Department of Health and Human Services, Office of the Surgeon General, Rockville, MD.
US Department of Health and Human Services, 2002. Physical Activity Fundamental To Preventing Disease. US Department of Health and Human Services, Assistant Secretary for Planning and Evaluation, Washington, D.C.
Veitch, J., Timperio, A., Crawford, D., Abbott, G., Giles-Corti, B., Salmon, J., 2011. Is the neighbourhood environment associated with sedentary behaviour outside of school hours among children? Annals of Behavioral Medicine 41, 333–341.
Wheeler, B.W., Cooper, A.R., Page, A.S., Jago, R., 2010. Greenspace and children's physical activity: a GPS/GIS analysis of the PEACH project. Preventive Medicine 51, 148–152.
Witten, K., Hiscock, R., Pearce, J., Blakely, T., 2008. Neighbourhood access to open spaces and the physical activity of residents: a national study. Preventive Medicine 47, 299–303.
Wolch, J., Jerrett, M., Reynolds, K., Mcconnell, R., Chang, R., Dahmann, N., Brady, K., Gilliland, F., Su, J.G., Berhane, K., 2010. Childhood obesity and proximity to urban parks and recreational resources: a longitudinal cohort study. Health & Place 17, 207–214.