# Locations of Physical Activity as Assessed by GPS in Young Adolescents

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abstract

**OBJECTIVES:** To compare adolescents' physical activity at home, near home, at school, near school, and at other locations.

**METHODS:** Adolescents (*N* = 549) were ages 12 to 16 years (49.9% girls, 31.3% nonwhite or Hispanic) from 447 census block groups in 2 US regions. Accelerometers and Global Positioning System devices assessed minutes of and proportion of time spent in moderate to vigorous physical activity (MVPA) in each of the 5 locations. Mixed-effects regression compared MVPA across locations and demographic factors.

**RESULTS:** Forty-two percent of adolescents' overall MVPA occurred at school, 18.7% at home, 18.3% in other (nonhome, nonschool) locations, and 20.6% near home or school. Youth had 10 more minutes (30% more) of overall MVPA on school days than on nonschool days. However, the percentage of location time spent in MVPA was lowest at school (4.8% on school days) and highest near home and near school (9.5%–10.4%). Girls had 2.6 to 5.5 fewer minutes per day of MVPA than boys in all locations except near school.

**CONCLUSIONS:** Although a majority of adolescents' physical activity occurred at school, the low proportion of active time relative to the large amount of time spent at school suggests potential for increasing school-based activity. Increasing time spent in the neighborhood appears promising for increasing overall physical activity, because a high proportion of neighborhood time was active. Increasing youth physical activity to support metabolic health requires strategies for increasing use of physical activity–supportive locations (eg, neighborhoods) and environmental and program improvements in unsupportive locations (eg, schools, homes).

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Dr Carlson conceptualized and carried out the analyses and drafted the initial manuscript; Dr Schipperijn and Mr Chapman designed the data collection instruments and carried out some of the spatial analyses; Drs Kerr, Saelens, Frank, Glanz, Conway, and Sallis conceptualized and designed the study and critically reviewed the manuscript; Dr Natarajan supervised the statistical analyses; Ms Cain designed the data collection instructions, coordinated and supervised data collection, and critically reviewed the manuscript; and all authors approved the final manuscript as submitted.

**DOI:** 10.1542/peds.2015-2430

Accepted for publication Oct 12, 2015

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**WHAT'S KNOWN ON THIS SUBJECT:** Adolescents are among the least physically active age groups and therefore are at risk for obesity and chronic disease. Multilevel strategies exist for supporting adolescent physical activity in different locations, but the relative contribution of different locations is unknown.

**WHAT THIS STUDY ADDS:** Adolescent physical activity could be increased by decreasing time spent indoors at home, increasing physical activity opportunities at school (where youth were less active), and increasing time spent in home and school neighborhoods (where youth were more active).

**To cite:** Carlson JA, Schipperijn J, Kerr J, et al. Locations of Physical Activity as Assessed by GPS in Young Adolescents. *Pediatrics.* 2016;137(1):e20152430

Public health guidelines advise that children and adolescents should obtain ≥60 minutes of moderate to vigorous physical activity (MVPA) daily[1] for physical and mental health[1] and cognition and academic performance.[2,3] Maintaining a physically active lifestyle[4–6] and healthy weight[7] during childhood are key factors in chronic disease prevention. Yet, based on objective data, only an estimated 8.0% of youth in the United States meet the 60-minutes-per-day guideline.[8] US adolescents are among the least physically active in the world.[9]

Physical activity occurs in multiple settings and locations, and many public health intervention recommendations are location specific (eg, school-based physical activity, home-based screen time, neighborhood walking).[1,10,11] A better understanding of where youth obtain and fail to obtain physical activity can inform public health practice (eg, promotion, intervention). Most previous studies investigating physical activity locations in youth have used self-report methods and focused primarily on the home or school,[12,13] with the exception of 2 Global Positioning System (GPS)-based studies conducted in Europe and 1 in Canada that may not generalize to the United States.[14–16] It is possible that different amounts of physical activity in specific locations account for some of the demographic differences often observed in youth physical activity, so understanding how locations relate to demographic differences in youth physical activity could inform location-specific intervention strategies to reduce health disparities.

In the current study, GPS and accelerometry were used to assess objectively the amount of time and physical activity participants accrued in 5 locations: at home, near home, at school, near school, and in all other locations. The aim was to better understand the relative importance of each location to adolescents' overall physical activity by comparing across locations the absolute amount of physical activity, in minutes per day, and the proportion of time in a location spent physically active. Whereas absolute minutes of activity in each location helps describe where adolescents' physical activity occurs, the proportion of location time spent physically active adjusts for the time spent in each location and thus better informs location-specific and time use interventions for increasing physical activity. Based on these findings, health interventions could aim to increase time spent in locations where a high proportion of time is spent physically active and improve environments in locations where a low proportion of time is spent physically active. An additional aim was to investigate whether physical activity in each location differed between school and nonschool days and by participant demographic and anthropometric characteristics.

## METHODS

### Participants and Procedures

Present analyses used data from the Teen Environment and Neighborhood (TEAN) study of built environments and physical activity conducted in the Baltimore, Maryland–Washington, DC and Seattle–King County, Washington metropolitan areas in 2009 to 2011. TEAN participants were 928 healthy adolescents ages 12 to 16 years and 1 of their parents, selected from 447 census block groups representing high or low walkability and high or low income.[17] Walkability is a concept from city planning that refers to the ability to walk from home to nearby destinations. A walkability index was created in a geographic information system from net residential density, road intersection density, mixed land use, and pedestrian design of retail space.[17] The sampling was designed to be balanced by age and gender and to approximate the ethnic distribution of the regions. Data collection occurred during the school year and was balanced by season across the block group types. A total of 2619 households with a child in the qualifying age range were contacted by phone, and 36% were enrolled in the study. Participation rate did not differ across the 4 block group types.

Present analyses included a subsample of 549 TEAN participants who wore an accelerometer and GPS tracker together for ≥1 valid school day and ≥1 valid nonschool day. Reasons for exclusion are shown in Supplemental Table 5. Participant demographic characteristics and MVPA did not differ significantly between the present subsample and the full sample.

### Measures

#### *Demographics and Anthropometrics*

Adolescents' age, gender, and ethnicity (white non-Hispanic versus nonwhite or Hispanic) were reported in an adolescent survey, and parents reported highest level of education (college degree versus other) in the family. Parents were provided detailed instructions on measuring and reporting their child's height (eg, stand with heels against wall, mark with pencil, use measuring tape) and weight (eg, remove shoes, use scale). BMI percentiles were derived from US Centers for Disease Control and Prevention 2000 growth charts.

#### *GPS Tracking*

Participants wore a GlobalSat DG-100 GPS tracker (GlobalSat, New Taipei City, Taiwan), with latitude and longitude data collected at 30-second epochs (ie, 1 fix every 30 seconds when GPS signal was attainable). Previous studies documented acceptable performance for tracking participants' time and location patterns in epidemiologic studies.[18] The Personal Activity and Location

Measurement System[19] Version 4 (Center for Wireless and Population Health Systems, La Jolla, CA) was used to merge GPS and accelerometer data and filter invalid GPS fixes caused by satellite interference. The devices were time synchronized during initialization and linked in the Personal Activity and Location Measurement System with a time stamp. Participants whose GPS indicated they never left their home over the 1-week monitoring period were considered to have not worn the device. Only days with ≥8 hours of GPS signal during accelerometer wear time were included (if accelerometer criteria were also met).

### *Physical Activity*

Participants wore an ActiGraph accelerometer (ActiGraph, Pensacola, FL) on a belt at their left iliac crest during waking hours, with acceleration recorded at 30-second epochs. Multiple ActiGraph models were used (7164, 85.2%; 71256, 5.1%; GT1M, 7.2%; GT3X, 2.5%), and model type was not associated with MVPA. MVPA was scored with the Evenson cutoff points for youth,[20] divided by 2 (ie, ≥1148 counts per 30-second epoch denoted MVPA), which has been shown to have excellent classification accuracy.[21] Groups of >60 sequential 30-second epochs with count = 0 were considered nonwear, thus excluding nonwear and nonwaking time from the data.

## Analyses

### *Spatial Analyses to Identify Time and MVPA in the 5 Locations of Interest*

Home and school addresses were geocoded and incorporated into ArcGIS (ESRI, Inc, Redlands, CA) to create buffers defining the 5 locations of interest: at home (50-m-radius circular buffer around the point resulting from geocoding of the home address), near home (1-km street network buffer around geocoded home point, excluding the at-home circular buffer), at school (15-m buffer around geocoded school parcel), near school (1-km street network buffer around geocoded school point, excluding the at-school parcel buffer), and all other locations (ie, any location not included in the aforementioned 4 locations). Next, the participant-specific location and GPS information were incorporated into a PostgreSQL database (PostgreSQL Global Development Group, Berkeley, CA), and spatial analyses were conducted to assess, for each GPS point and each of the aforementioned locations, whether the GPS point was in the location. This information was used to calculate minutes per day of time and MVPA for each location. No participants had overlap in their at-home and at-school buffers, and 110 participants had overlap in their near-home and near-school buffers. The overlapping time and MVPA was divided by 2 and split evenly across the near-home and near-school buffers. School days were defined as any weekday the GPS showed the participant at school for ≥200 minutes.

### *Statistical Analyses*

All models were mixed-effects random intercept linear regression models, fitted with the “MIXED” command in SPSS version 22 (IBM SPSS Statistics, IBM Corporation),[22] to account for the nested data structure. Differences in MVPA minutes and percentage of location time in MVPA across locations were assessed with location as a categorical repeated-effects independent variable. Percentage of location time in MVPA was calculated as location MVPA ÷ location time * 100. Models were estimated separately for school days, nonschool days, and a weighted week, which was calculated as ([mean daily minutes across school days * 5] + [mean daily minutes across nonschool days * 2] ÷ 7).

Next, demographic differences were assessed by regressing minutes per day of time, MVPA, and percentage of location time in MVPA (in separate models) on participant age, gender, race or ethnicity, and BMI percentile; parent education; and whether the participant was at school. Separate models were estimated for each location, and models were adjusted for neighborhood walkability (high versus low) and household income (high versus low) because these were study design factors. All independent variables were mean centered (continuous variables) or centered on zero (dichotomous variables), so the model intercepts would approximate the overall sample mean for the dependent variables. Unstandardized regression coefficients (B) are reported and can be interpreted as minutes per day or percentage of time in MVPA. Percentage differences between demographic categories, or for a 1-year increase in age or 10-percentile increase in BMI, were calculated by dividing the regression coefficient by the mean value for reference group.

## Ethics Statement

This study was approved by the University of California, San Diego Institutional Review Board. Written informed assent and parental consent were provided.

## RESULTS

Mean participant age was 14.1 (SD = 1.4) years, 49.9% were girls, 31.3% were nonwhite or Hispanic, 64.7% had a parent with a college degree, and 10% were obese (mean BMI percentile = 64.0; SD = 26.6). Participants wore both the GPS and the accelerometer for a mean of 7.0 (SD = 1.5) valid days. Across the weighted week, participants spent the largest part (42.1%) of their waking time at school, followed by at home (27.7%), with less time in other locations (14.1%), near home

(12.6%), and near school (3.5%; Supplemental Fig 3 and Supplemental Table 6). The only participant characteristic associated with time spent in any of the locations was participant age, which was positively associated with time spent in other locations (Supplemental Table 7).

## MVPA Minutes Overall and in Each Location (Not Adjusted for Time in Location)

Participants had a mean of 39.4 (SD = 20.1) minutes per day of MVPA across all locations, with 55.2% of overall MVPA minutes on school days and 42.4% of overall MPVA minutes during the weighted week occurring at school. On nonschool days, the locations with the most MVPA minutes were the at-home location (37.4% of overall MVPA) and other locations (34.3% of overall MVPA; Fig 1 and Table 1).

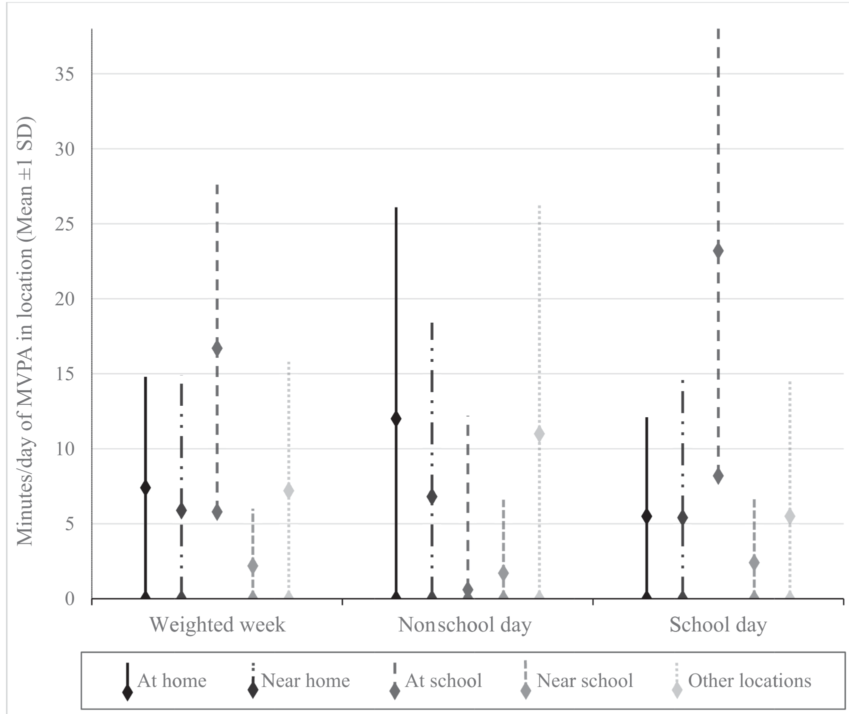


**FIGURE 1**
MVPA minutes per day accrued in primary and other locations on school and nonschool days (*N* = 549).

**TABLE 1** Differences in MVPA Minutes per Day Accrued in Primary and Other Locations on School and Nonschool Days (*N* = 549)

| | MVPA min/d in Each Location | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Weighted Week | | | Nonschool Days | | | School Days | | |
| | Mean (SD), min/d | % of Overall MVPA | Significant Differences[a] | Mean (SD), min/d | % of Overall MVPA | Significant Differences[a] | Mean (SD), min/d | % of Overall MVPA | Significant Differences[a] |
| All locations | 39.4 (20.1) | — | — | 32.1 (21.8) | — | — | 42.0 (22.5) | — | — |
| a. At home | 7.4 (7.4) | 18.7 | b*, c**, d** | 12.0 (14.1) | 37.4 | b**, c**, d** | 5.5 (6.6) | 13.1 | c**, d** |
| b. Near home | 5.9 (9.0) | 15.0 | a*, c**, d** | 6.8 (11.6) | 21.2 | a**, c**, d**, e** | 5.4 (9.2) | 12.9 | c**, d** |
| c. At school | 16.7 (10.9) | 42.4 | a**, b**, d**, e** | 0.6 (11.6) | 1.8 | a**, b**, d**, e** | 23.2 (15.0) | 55.2 | a**, b**, d**, e** |
| d. Near school | 2.2 (3.8) | 5.6 | a**, b**, c**, e** | 1.7 (4.9) | 5.3 | a**, b**, c**, e** | 2.4 (4.3) | 5.7 | a**, b**, c**, e** |
| e. Other locations | 7.2 (8.6) | 18.3 | c**, d** | 11.0 (15.4) | 34.3 | b**, c**, d** | 5.5 (9.0) | 13.1 | c**, d** |

[a] From mixed-effects linear regression models adjusted for nesting of locations within participants and participants within block groups.
* *P* < .05;
** *P* < .001.

The relations of participant characteristics to minutes per day of MVPA in each location are presented in Table 2 for the weighted week. On school days, participants had more MVPA minutes per day at school and near school, and fewer MVPA minutes per day at home, near home, and in other locations, as compared with nonschool days. Older participants had fewer MVPA minutes per day at home compared with younger participants, but age was not associated with MVPA in any other location. Girls had fewer MVPA minutes per day in all locations as compared with boys, with the exception of near school. Participant race or ethnicity and parent education were not associated with MVPA minutes per day in any location. Participant BMI was associated with overall MVPA minutes per day across locations.

## Proportion of Time in Each Location Spent Physically Active

Taking into account time spent in each location, the proportion of location time in MVPA was highest for the near-home and near-school locations on school days (10.3%–10.4%) and the weighted week (9.5%–9.7%), with at school lower than all other locations except at home (Fig 2 and Table 3). On

**TABLE 2** Relation of School Day (y/n) and Participant Demographic and Anthropometric Characteristics to MVPA Minutes per Day in Each Location ($N = 549$)

| | MVPA in Each Location | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | All Locations | | | At Home | | | Near Home | | | At School | | | Near School | | | Other Locations | | |
| | B (95% CI), min/d | % Difference[a] | *P* | B (95% CI), min/d | % Difference[a] | *P* | B (95% CI), min/d | % Difference[a] | *P* | B (95% CI), min/d | % Difference[a] | *P* | B (95% CI), min/d | % Difference[a] | *P* | B (95% CI), min/d | % Difference[a] | *P* |
| Weighted grand mean | 39.4 | — | — | 7.4 | — | — | 5.9 | — | — | 16.7 | — | — | 2.2 | — | — | 7.2 | — | — |
| School day (vs nonschool day) | 9.3 (7.9 to 10.8) | 26.8 | <.001 | −6.8 (−7.6 to −6.0) | −63.0 | <.001 | −1.4 (−2.1 to −0.7) | −21.2 | <.001 | 22.7 (21.8 to 23.6) | 424.3 | <.001 | 0.5 (0.1 to 0.9) | 25.6 | .015 | −5.6 (−6.6 to 4.6) | −56.0 | <.001 |
| Age, y | −0.7 (−1.8 to 0.3) | −1.8 | .163 | −0.7 (−1.2 to −0.2) | −9.0 | .007 | −0.3 (−0.8 to 0.3) | −5.0 | .326 | 0.5 (−0.5 to 0.6) | 3.0 | .863 | 0 (−0.3 to 0.2) | 0 | .772 | 0.2 (−0.3 to 0.8) | 2.8 | .365 |
| Girls (vs boys) | −15.0 (−18.1 to 12.0) | −32.0 | <.001 | −3.7 (−5.2 to −2.2) | −40.0 | <.001 | −2.6 (−4.2 to −1.0) | −36.1 | .001 | −5.5 (−7.0 to −3.9) | −28.3 | <.001 | −0.6 (−1.2 to 0.1) | −24.0 | .094 | −2.6 (−4.1 to −1.2) | −30.6 | .001 |
| White non-Hispanic (vs nonwhite or Hispanic) | −0.9 (−4.2 to 2.4) | −2.3 | .585 | 0.1 (−1.5 to 1.7) | 1.4 | .920 | −1.4 (−3.1 to 0.4) | −21.2 | .121 | 0.4 (−1.3 to 2.1) | 2.4 | .654 | −0.5 (−1.2 to 0.2) | −20.4 | .186 | 0.5 (−1.1 to 2.1) | 7.2 | .519 |
| Parent ≥college grad (vs parent <college grad) | 0.3 (−3.0 to 3.5) | 0.8 | .875 | 1.4 (−0.2 to 3.0) | 20.9 | .078 | −1.1 (−2.9 to 0.6) | −17.1 | .194 | 0.2 (−1.4 to 1.9) | 1.2 | .779 | 0.3 (−0.4 to 1.1) | 14.6 | .345 | −0.6 (−2.2 to 1.0) | −8.0 | .481 |
| BMI (percentile/10) | −0.7 (−1.3 to −0.2) | −1.8 | .011 | −0.1 (−0.3 to 0.2) | −1.3 | .629 | −0.3 (−0.6 to 0) | −5.0 | .065 | −0.3 (−0.6 to 0) | −1.8 | .085 | 0 (−0.1 to 0.1) | 0 | .848 | −0.1 (−0.4 to 0.1) | −1.4 | .325 |

From mixed-effects linear multivariable regression models adjusted for neighborhood income and walkability and nesting of days within participants and participants within block groups. B, unstandardized regression coefficient, interpreted as minutes per day of MVPA; CI, confidence interval.

[a] Difference between the 2 demographic categories of interest (reference category is in parentheses) or for a 1-y increase in age or 10-percentile increase in BMI.

nonschool days, the proportion of location time in MVPA was approximately equal across the locations (4.6%–7.7%), except near home had a higher proportion of time in MVPA than at-home time.

The relations of participant characteristics to percentage of location time spent in MVPA are presented in Table 4 for the weighted week. The percentage of location time spent in MVPA was higher on school days as compared with nonschool days for the at-home, near-home, and near-school locations and lower for the at-school location . Girls had a lower percentage of location time spent in MVPA as compared with boys for all locations except at home. Participant age, race or ethnicity, and parent education were not associated with the percentage of location time spent in MVPA in any location.

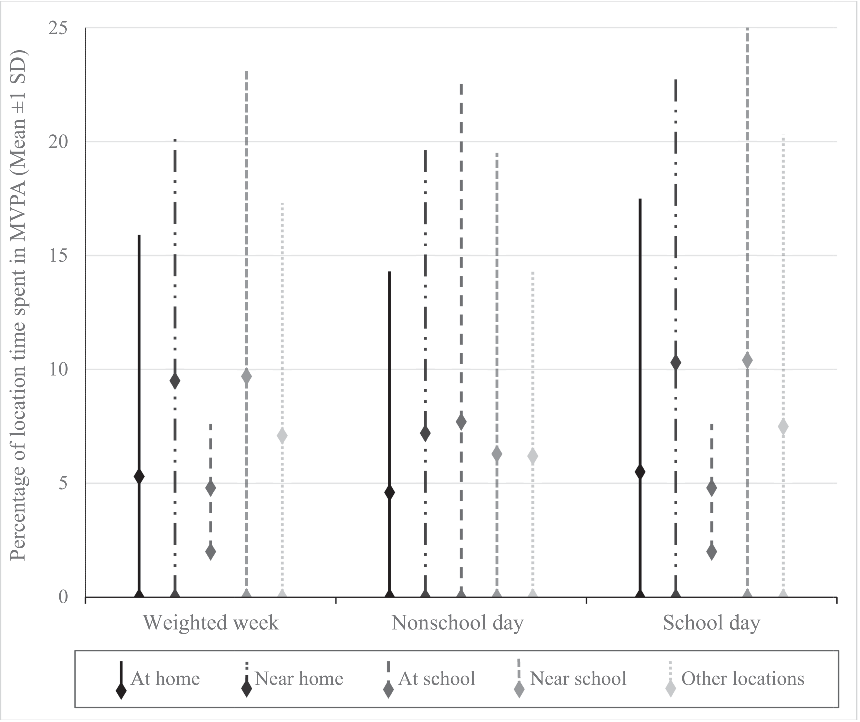


**FIGURE 2**
Proportion of location time spent in MVPA on school and nonschool days ($N$ = 549).

**TABLE 3** Differences in Proportion of Location Time Spent in MVPA on School and Nonschool Days ($N$ = 549)

| | Proportion of Location Time Spent in MVPA | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Weighted Week | | | Nonschool Days | | | School Days | | |
| | $N$ | Mean (SD), Proportion | Significant Differences[a] | $N$[b] | Mean (SD), Proportion | Significant Differences[a] | $N$[b] | Mean (SD), Proportion | Significant Differences[a] |
| All locations | 549 | 4.8% (0.2) | — | 549 | 4.3% (2.9) | — | 549 | 5.0% (2.6) | — |
| a. At home | 549 | 5.3% (10.6) | b*, d*, e** | 518 | 4.6% (9.7) | b** | 535 | 5.5% (12.0) | b*, d* |
| b. Near home | 549 | 9.5% (10.9) | a*, c*, e** | 522 | 7.2% (12.7) | a** | 540 | 10.3% (12.6) | a*, c*, e** |
| c. At school | 549 | 4.8% (2.8) | b*, d*, e* | 204 | 7.7% (14.9) | None | 546 | 4.8% (2.8) | b*, d*, e* |
| d. Near school | 549 | 9.7% (13.5) | a*, c*, e** | 274 | 6.3% (13.2) | None | 538 | 10.4% (14.7) | a*, c*, e** |
| e. Other locations | 549 | 7.1% (10.2) | a**, b*, c*, d** | 473 | 6.2% (8.1) | None | 523 | 7.5% (12.8) | b**, c*, d** |

[a] From mixed-effects linear regression models adjusted for nesting of locations within participants and participants within block groups.
[b] If a participant did not spend any time in a given location on school days or nonschool days, then the "percentage of location time in MVPA" variable was entered as missing. Thus, because mixed models were used, a participant who was missing a given location still contributed to estimating the parameters for the nonmissing locations.
* $P < .001$.
** $P < .05$;

## DISCUSSION

Present findings highlight the relative importance of various locations to adolescents' physical activity, which informs place-based health interventions. Youth had more overall physical activity minutes at school than in any of the 4 other locations. However, the proportion of time at school that was spent physically active was lower than in all other locations except at home. Because adolescents spend so much time at school, even a small increase in the proportion of at-school time spent physically active could lead to meaningful increases in overall physical activity and metabolic health. The home neighborhood and, to a lesser extent, school neighborhood appeared to be promising locations for supporting increases in physical activity because a greater proportion of time spent in these locations was physically active, as compared with the other locations assessed. Gender differences in physical activity minutes and proportion of time spent physically active in a location were fairly consistent across locations, with girls having less physical activity than boys in all locations. Findings support the call for interventions across multiple settings for improving adolescents' physical activity and health (eg, National Physical Activity Plan[23]).

**TABLE 4** Relation of School Day (y/n) and Participant Demographic and Anthropometric Characteristics to Proportion of Location Time Spent in MVPA (*N* = 549)

| | Proportion of Location Time Spent in MVPA | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | All Locations | | | At Home | | | Near Home | | | At School | | | Near School | | | Other Locations | | |
| | B (95% CI), Proportion | % Difference[a] | *P* | B (95% CI), Proportion | % Difference[a] | *P* | B (95% CI), Proportion | % Difference[a] | *P* | B (95% CI), Proportion | % Difference[a] | *P* | B (95% CI), Proportion | % Difference[a] | *P* | B (95% CI), Proportion | % Difference[a] | *P* |
| Weighted grand mean | 4.8% | — | — | 5.3% | — | — | 9.5% | — | — | 4.8% | — | — | 9.7% | — | — | 7.1% | — | — |
| School day (vs nonschool day) | 0.7% (0.5 to 0.9) | 15.7 | <.001 | 1.2% (0.5 to 1.9) | 25.5 | .001 | 4.0% (3.0 to 4.9) | 53.3 | <.001 | −3.3% (−4.1 to −2.4) | −51.2 | <.001 | 6.1% (4.3 to 7.8) | 91.7 | <.001 | 0.3% (−0.6 to 1.3) | 4.3 | .479 |
| Age, y | −0.1% (−0.2 to 0) | −2.1 | .135 | 0.4% (−0.2 to 0.9) | 7.8 | .212 | 0.2% (−0.4 to 0.1) | 2.1 | .506 | 0.1% (−0.2 to 0.3) | 2.1 | .575 | 0.4% (−0.4 to 1.1) | 4.2 | .438 | 0.2% (−0.3 to 0.8) | 2.9 | .397 |
| Girls (vs boys) | −1.8% (−2.1 to −1.4) | −31.6 | <.001 | −0.6% (−2.2 to 1.0) | −10.7 | .434 | −2.7% (−4.3 to −1.0) | −24.9 | .001 | −2.1% (−2.8 to −1.5) | −35.9 | <.001 | −5.1% (−7.3 to −2.9) | −41.6 | <.001 | −2.1% (−3.8 to −0.5) | −25.8 | .011 |
| White non-Hispanic (vs nonwhite or Hispanic) | 0% (−0.4 to 0.4) | 0 | .957 | −0.2% (−1.9 to 1.5) | −3.7 | .797 | 0% (−1.7 to 1.8) | 0 | .988 | 0.1% (−0.6 to 0.8) | 2.1 | .835 | −1.0% (−3.4 to 1.5) | −9.8 | .436 | 0.9% (−0.9 to 2.6) | 13.5 | .344 |
| Parent ≥college grad (vs parent <college grad) | 0.1% (−0.3 to 0.4) | 2.1 | .749 | −0.6% (−2.3 to 1.1) | −10.7 | .478 | −0.6% (−2.4 to 1.1) | −6.1 | .490 | −0.2% (−0.9 to 0.5) | −4.1 | .664 | 1.3% (−1.1 to 3.7) | 14.4 | .297 | −0.1% (−1.9 to 1.7) | −1.4 | .896 |
| BMI (percentile/10) | −0.1% (−0.1 to 0) | −2.1 | .011 | 0.1% (−0.2 to 0.4) | 1.9 | .533 | −0.3% (−0.6 to 0) | −3.1 | .055 | −0.1% (−0.2 to 0) | −2.1 | .170 | −0.2% (−0.6 to 0.2) | −2.0 | .390 | −0.2% (−0.5 to 0.1) | −2.8 | .263 |

From mixed-effects linear multivariable regression models adjusted for neighborhood income and walkability and nesting of days within participants and participants within block groups. B, unstandardized regression coefficient, interpreted as percentage of location time spent in MVPA; CI, confidence interval.

[a] Difference between the 2 demographic categories of interest (reference category is in parentheses) or for a 1-y increase in age or 10-percentile increase in BMI.

The at-school location was clearly an important contributor to participants' physical activity, with 42% of participants' weekly (including nonschool days) physical activity occurring at school. However, participants spent a great deal of their waking time at school (42% of device wear time), and the proportion of at-school time being physically active was the lowest of all locations (4.8%). It is possible that some of the at-school physical activity occurred before or after school, for example, during sports or afterschool programs, and that physical activity minutes and the proportion of time spent physically active during school hours was even lower than reported. Based on the US average school day length of 6.64 hours,[24] youth would need to spend about 7.5% of their school time (4.5 minutes/hour) in physical activity to meet the 30-minutes-per-day guideline for physical activity during school.[25,26] There are several evidence-based and feasible approaches for increasing physical activity at school, including highly active physical education curricula and activity breaks in classrooms.[11,27]

Because youth had >25% more physical activity on school days than nonschool days, home environment and community-based interventions are particularly needed to support physical activity on nonschool days. On nonschool days, a majority of participants' overall physical activity minutes occurred at-home and at other locations. However, the percentage of at-home time spent physically active was as low as that of at-school time (4.8%). This lack of activity could have resulted from competing sedentary activities in the home and an unsuitable environment for physical activity (note that nonwaking hours were excluded from analyses). It is likely that physical activity accrued in other locations, wherein a higher proportion of time was active as compared with at-home and at-school time, included sports and recreation areas outside the home and school neighborhoods. Previous research assessing land use type of physical activity locations in youth suggests that nonhome and nonschool physical activity is spread across multiple land use types, including green spaces, streets, retail locations, and other residential locations.[14–16]

Although a small amount of overall physical activity occurred near home and near school (ie, the home and school neighborhoods), these locations may be the most promising for intervention. This is because the proportion of location time spent in physical activity for the near-home and near-school locations, ~10%, was higher than for the other 3 locations assessed. This neighborhood-based physical activity probably included active travel to and from school and recreational activities in the neighborhood. Thus, increasing time in home and school neighborhoods might increase physical activity, partly by reducing time spent in less active locations. Supporting neighborhood-based activity through organized programs and informal supervision could improve parents' perceptions of safety and may lead them to allow their adolescents to spend more time outdoors being active in the neighborhood. Increasing active travel remains an intervention priority, because active travel is a significant contributor to overall physical activity, but current rates are low.[28,29] Safe Routes to School programs have been effective in increasing walking and bicycling to and from school.[30,31]

The present finding that boys had more minutes per day of physical activity than girls, not only overall but also in each location, indicates that gender disparities must be addressed in all settings. Active Physical Education[32] is an example of a setting-specific evidence-based intervention shown to provide similar amounts of physical activity for both genders. Similar to the findings on gender differences, the BMI–physical activity association did not appear to be location specific, although the associations in each location were small, and only the association across all locations was significant.

A positive finding was that neither race and ethnicity nor parent education differences were found for overall or location-specific physical activity. However, this sample used a stratified design, with socioeconomic status being distributed equally across high- and low-walkable neighborhoods. So it is possible that socioeconomic status disparities exist but were not observed in this sample.

The current study used GPS and accelerometry to objectively assess physical activity locations in a large sample of adolescents in 2 US regions. Besides improving understanding of the relative importance of various locations to total physical activity, location-specific measures allow more precise investigation of environmental influences on physical activity and evaluation of setting-based interventions. It is common for GPS signals to be somewhat unreliable when indoors, so there could have been misclassification when assessing whether participants were at home versus near home and at school versus near school. Some GPS devices (not the device used in this study) allow assessment of when participants are indoors or outdoors, which could be used in future studies to minimize misclassification of physical activity locations and support investigation of indoor versus outdoor activity. The observational nature of this study limits understanding of whether spending more or less time in specific locations would lead to increases in adolescents' physical activity (ie, mobility bias).[33] Lack of specificity about the nature of other locations was a limitation. The sample was not selected to be spatially or otherwise representative but rather was recruited to ensure variability in neighborhood walkability environment and income.

## CONCLUSIONS

Supporting youth to meet the recommended 60 minutes/day of physical activity[1] requires a coordinated approach that enables youth to incorporate physical activity in multiple locations. Effective intervention strategies probably differ by location. The consistency of gender disparities in physical activity across locations suggests that gender-specific strategies are needed in all settings. Although a large amount of participants' overall physical activity occurred at school, the low proportion of at-school time spent physically active suggests room for improvement through implementation of evidence-based school-focused strategies.[27] The low proportion of at-home time spent physically active suggests that interventions to increase in-home physical activity are needed. The low rates of active travel and neighborhood-based physical activity require multilevel interventions targeting built environment improvements and social support. Health care providers can advocate for youth physical activity by engaging in local planning and decision-making processes to increase use of neighborhood locations that support physical activity and to improve facilities and physical activity programs in all settings. Health care providers can advise parents to encourage their children to spend less time at home and more time in home and school neighborhoods where youth are more likely to engage in physical activity.

### ABBREVIATIONS

GPS: Global Positioning System
MVPA: moderate to vigorous physical activity
TEAN: Teen Environment and Neighborhood

PEDIATRICS (ISSN Numbers: Print, 0031-4005; Online, 1098-4275).



**FINANCIAL DISCLOSURE:** The authors have indicated they have no financial relationships relevant to this article to disclose.

**FUNDING:** Funded by National Institutes of Health (NIH) grant HL083454, and the lead author was funded by NIH T32 HL079891. Funded by the National Institutes of Health (NIH).

**POTENTIAL CONFLICT OF INTEREST:** The authors have indicated they have no potential conflicts of interest to disclose.

## REFERENCES

1. US Department of Health and Human Services2008. Physical activity guidelines for Americans. Available at: www.health.gov/paguidelines/pdf/paguide.pdf Accessed January 15, 2015
2. Rasberry CN, Lee SM, Robin L, et al. The association between school-based physical activity, including physical education, and academic performance: a systematic review of the literature. *Prev Med*. 2011;52(suppl 1):S10–S20
3. Sibley B, Etnier J. The relationship between physical activity and cognition in children: a meta-analysis. *Pediatr Exerc Sci*. 2003;15(3):243–256
4. Gordon-Larsen P, Nelson MC, Popkin BM. Longitudinal physical activity and sedentary behavior trends: adolescence to adulthood. *Am J Prev Med*. 2004;27(4):277–283
5. Telama R, Yang X, Viikari J, Välimäki I, Wanne O, Raitakari O. Physical activity from childhood to adulthood: a 21-year tracking study. *Am J Prev Med*. 2005;28(3):267–273
6. Gutin B, Owens S. The influence of physical activity on cardiometabolic biomarkers in youths: a review. *Pediatr Exerc Sci*. 2011;23(2):169–185
7. Dietz WH. Health consequences of obesity in youth: childhood predictors of adult disease. *Pediatrics*. 1998;101(3 pt 2):518–525
8. Troiano RP, Berrigan D, Dodd KW, Mâsse LC, Tilert T, McDowell M. Physical activity in the United States measured by accelerometer. *Med Sci Sports Exerc*. 2008;40(1):181–188
9. Hallal PC, Andersen LB, Bull FC, Guthold R, Haskell W, Ekelund U; Lancet Physical Activity Series Working Group. Global physical activity levels: surveillance progress, pitfalls, and prospects. *Lancet*. 2012;380(9838):247–257
10. Office of Disease Prevention and Health Promotion. Healthy People 2020. Available at: www.healthypeople.gov/2020/topics-objectives/topic/physical-activity. Accessed March 27, 2015
11. Institute of Medicine (IOM). *Educating the Student Body: Taking Physical Activity and Physical Education to School*. Washington, DC: The National Academies Press; 2013
12. Grow HM, Saelens BE, Kerr J, Durant NH, Norman GJ, Sallis JF. Where are youth active? Roles of proximity, active transport, and built environment. *Med Sci Sports Exerc*. 2008;40(12):2071–2079
13. Kneeshaw-Price S, Saelens BE, Sallis JF, et al. Children's objective physical activity by location: why the neighborhood matters. *Pediatr Exerc Sci*. 2013;25(3):468–486
14. Jones AP, Coombes EG, Griffin SJ, van Sluijs EMF. Environmental supportiveness for physical activity in English schoolchildren: a study using Global Positioning Systems. *Int J Behav Nutr Phys Act*. 2009;6:42
15. Klinker CD, Schipperijn J, Christian H, Kerr J, Ersbøll AK, Troelsen J. Using accelerometers and Global Positioning System devices to assess gender and age differences in children's school, transport, leisure and home based physical activity. *Int J Behav Nutr Phys Act*. 2014;11:8
16. Rainham DG, Bates CJ, Blanchard CM, Dummer TJ, Kirk SF, Shearer CL. Spatial classification of youth physical activity patterns. *Am J Prev Med*. 2012;42(5):e87–e96
17. Frank LD, Sallis JF, Saelens BE, et al. The development of a walkability index: application to the Neighborhood Quality of Life Study. *Br J Sports Med*. 2010;44(13):924–933
18. Wu J, Jiang C, Liu Z, Houston D, Jaimes G, McConnell R. Performances of different global positioning system devices for time–location tracking in air pollution epidemiological studies. *Environ Health Insights*. 2010;4:93–108
19. Center for Wireless & Population Health Systems. Personal Activity and Location Measurement System (PALMS). Available at: http://ucsd-palms-project.wikispaces.com/. Accessed February 27, 2015
20. Evenson KR, Catellier DJ, Gill K, Ondrak KS, McMurray RG. Calibration of two objective measures of physical activity for children. *J Sports Sci*. 2008;26(14):1557–1565
21. Trost SG, Loprinzi PD, Moore R, Pfeiffer KA. Comparison of accelerometer cut points for predicting activity intensity in youth. *Med Sci Sports Exerc*. 2011;43(7):1360–1368
22. IBM Corp. *IBM SPSS Statistics for Windows, Version 22.0*. Armonk, NY: IBM Corp; 2013
23. National Center for Education Statistics. National Physical Activity Plan. Available at: www.physicalactivityplan.org/theplan.php. Accessed March 16, 2015
24. National Center for Education Statistics. Schools and Staffing Survey (SASS). 2007–08. Available at: https://nces.ed.gov/surveys/sass/tables/sass0708_035_s1s.asp. Accessed May 19, 2015
25. Centers for Disease Control and Prevention (CDC). School health guidelines to promote healthy eating and physical activity. *MMWR Recomm Rep*. 2011;60(RR-5):1–76
26. Pate RR, Davis MG, Robinson TN, Stone EJ, McKenzie TL, Young JC; American Heart Association Council on Nutrition, Physical Activity, and Metabolism

(Physical Activity Committee); Council on Cardiovascular Disease in the Young; Council on Cardiovascular Nursing. Promoting physical activity in children and youth: a leadership role for schools: a scientific statement from the American Heart Association Council on Nutrition, Physical Activity, and Metabolism (Physical Activity Committee) in collaboration with the Councils on Cardiovascular Disease in the Young and Cardiovascular Nursing. *Circulation*. 2006;114(11):1214–1224

27. Physical Activity Guidelines for Americans Midcourse Report Subcommittee of the President's Council on Fitness, Sports & Nutrition. *Physical Activity Guidelines for Americans Midcourse Report: Strategies to Increase Physical Activity Among Youth*. Washington, DC: US Department of Health and Human Services; 2012

28. Carlson JA, Saelens BE, Kerr J, et al. Association between neighborhood walkability and GPS-measured walking, bicycling and vehicle time in adolescents. *Health Place*. 2015;32:1–7

29. Cooper AR, Andersen LB, Wedderkopp N, Page AS, Froberg K. Physical activity levels of children who walk, cycle, or are driven to school. *Am J Prev Med*. 2005;29(3):179–184

30. Stewart O, Moudon AV, Claybrooke C. Multistate evaluation of safe routes to school programs. *Am J Health Promot*. 2014;28(3 suppl):S89–S96

31. McDonald N, Steiner R, Lee C, Rhoulac Smith T, Zhu X, Yang Y. Impact of the Safe Routes to School Program on walking and bicycling. *J Am Plann Assoc*. 2014;80(2):153–167

32. Sallis JF, McKenzie TL, Alcaraz JE, Kolody B, Faucette N, Hovell MF. The effect of a 2-year physical education program (SPARK) on physical activity and fitness in elementary school students. Sports, Play and Active Recreation for Kids. *Am J Public Health*. 1997;87(8):1328–1334

33. Chaix B, Méline J, Duncan S, et al. GPS tracking in neighborhood and health studies: a step forward for environmental exposure assessment, a step backward for causal inference? *Health Place*. 2013;21:46–51