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Association between neighborhood walkability and GPS-measured walking, bicycling and vehicle time in adolescents

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Abstract

Objectives—To investigate relations of walking, bicycling and vehicle time to neighborhood walkability and total physical activity in youth.

Methods—Participants (N=690) were from 380 census block groups of high/low walkability and income in 2 US regions. Home neighborhood residential density, intersection density, retail density, entertainment density and walkability were derived using GIS. Minutes/day of walking, bicycling and vehicle time were derived from processing algorithms applied to GPS. Accelerometers estimated total daily moderate-to-vigorous physical activity (MVPA). Models were adjusted for nesting of days (N=2987) within participants within block groups.

Results—Walking occurred on 33%, active travel on 43%, and vehicle time on 91% of the days observed. Intersection density and neighborhood walkability were positively related to walking and bicycling and negatively related to vehicle time. Residential density was positively related to walking.

Conclusions—Increasing walking in youth could be effective in increasing total physical activity. Built environment findings suggest potential for increasing walking in youth through improving neighborhood walkability.

Keywords

density; land use; mode share; physical activity; transportation

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Transportation-related behaviors are understudied contributors to youth physical activity and sedentary behavior. Walking and bicycling to and from school are consistently related to more total physical activity in youth.[1–4] However, US adolescents report low rates of walking and bicycling; only 10–25% of adolescents report any walking or bicycling to school[5–8] and findings from the 2009 US Household Transportation survey indicated that 24% of youth had no walking or bicycling trips during the 7-day assessment period.[9] Understanding more about factors impacting travel behaviors, particularly among adolescents who are transitioning to more independent mobility, could inform interventions to increase physical activity and decrease sedentary behavior.

Macro-level built environment characteristics can affect large portions of the population and potentially create opportunities for sustained increases in walking and bicycling and decreases in vehicle time.[10,11] However this has seldom been investigated in youth with the exception of walking to and from school.[12–14] Positive associations between residential density and walking have been the strongest and most consistent findings in youth. Studies have also found fairly strong and consistent associations between increased land use mix and walking in adolescents. Thus far, there have been weaker and inconsistent findings for greater street connectivity.[12–14]

A limitation of prior studies examining walking, bicycling and vehicle time is that they have relied upon self-reported data (e.g., travel logs), despite the known limitations of such methods, particularly misestimation.[15,16] Misestimation could attenuate or obscure relationships with built environment characteristics. Another limitation of prior studies is that few have simultaneously examined whether macro-level built environment correlates differed for adolescents' walking vs. bicycling vs. vehicle time or whether the same correlates exist but with opposite valences. The majority of the evidence regarding adults supports that neighborhood built environment characteristics are related to vehicle miles traveled, but in the opposite direction of the associations with active transportation.[14,17] Studies from the transportation field often report number of trips and miles traveled by mode (rather than time),[9,18] but time spent walking, bicycling and in vehicle is important for understanding health implications, particularly those related to energy expenditure.

The present study assessed adolescents' time spent walking, bicycling and in a vehicle using validated processing algorithms applied to Global Positioning Systems (GPS) data in adolescents. The objectives were to investigate relations of (1) minutes/day in each trip mode to total physical activity and sedentary time at the day level, and (2) macro-level objective home neighborhood built environment characteristics to time spent in each trip mode. Findings could inform neighborhood modification efforts to support walking and bicycling and reduce vehicle time.

METHODS

Participants and Procedures

Present analyses used data from the Teen Environment and Neighborhood (TEAN) study of neighborhood environments and physical activity that was conducted in the Baltimore, Maryland/Washington, DC and Seattle/King County, Washington metropolitan areas during 2009–2011. TEAN participants were 928 adolescents and one of their parents, selected from 447 census block groups representing high or low walkability and high or low income (i.e., four block group types based on built environment measures of walkability and median household income from Census 2000 data, using methods similar to those described in a previous study).[19] Deciles were created for block group income and walkability, with 10% of the block groups within each metropolitan area (2,366 block groups in the Baltimore, MD region and 1,580 block groups in the Seattle, WA region) comprising each decile. The 1st through 4th deciles constituted the "low" category, and the 7th through 10th deciles constituted the "high" category, with the exception that the 10th income decile was omitted to avoid outliers in neighborhood income. The 5th and 6th deciles were omitted to create separation between the categories. Households with adolescents aged 12–16 were identified from a list purchased from a marketing company. The sampling was designed to be balanced by age and gender and to approximate the ethnic distribution of the regions. Adolescents were ineligible if they had a condition affecting their physical activity (e.g., physical disability), dietary habits (e.g., eating disorder), or ability to participate (e.g., developmental disability). Enrolled participants were mailed an accelerometer and a GPS device with instructions to wear the devices for one week during all waking hours.

Data collection occurred during the spring, fall, and winter seasons and was balanced by season across the block group types. A total of 2619 eligible households (i.e., having 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. Participant characteristics were generally similar to characteristics of the included block groups obtained from the

2010 US Census. Our sample included a similar proportion of White non-Hispanics as compared to the proportion represented in the included block groups (61% vs. 55% in the Baltimore, MD region and 73% vs. 71% in the Seattle, WA region). A greater proportion of our sample had a parent with a college degree as compared to the proportion represented in the included block groups (64% vs. 30% in the Baltimore, MD region and 64% vs. 38% in the Seattle, WA region), which is common in survey research.

Measures

GPS-derived trips. Participants wore a GlobalSat DG-100 GPS device, with latitude and longitude data collected at 30-second epochs (i.e., one fix every 30 seconds when GPS signal was attainable). Previous studies have found this device to have acceptable performance for tracking participants' time location patterns in epidemiological studies.[20] The Personal Activity and Location Measurement System (PALMS)[21] Version 4 was used to merge GPS and accelerometer data, filter invalid GPS fixes caused by satellite interference, and identify trips and trip mode. PALMS trip detection uses a similar logic model as the one outlined by Cho et al.[22] but allows the user to set parameters.

Distance and speed between every sequential fix (yielding a latitude and longitude coordinate in GPS) were computed in PALMS. Groups of sequential fixes (≥4 fixes) were considered trips if they spanned ≥100 meters with an average speed across fixes of ≥1.5 km/hour. Pauses ≤5 minutes were allowed during a trip to account for circumstances such as stop lights, but not at the trip origin or destination. Traveling within a location (e.g., home or school) was not considered part of a trip, with locations being defined as 30-meter radial buffers around every group of ≥5 sequential fixes that did not meet criteria for being considered a trip.

Trips with a 90th percentile speed of ≥25 km/hour were classified as vehicle trips, trips with a 90th percentile speed ≥9 and <25 km/hour were classified as bicycling/ other wheeled trips, and trips with a 90th percentile speed <9 km/hour were classified as walking trips. To eliminate pauses from walking trips, fixes during walking trips with accelerometer values <500 counts per 30-second epoch were not considered walking time.

Classification accuracy of the PALMS trip detection algorithms in free-living environments was assessed using annotated "ground truth" from SenseCam (i.e., camera worn around the neck that takes multiple images every minute) in a validation study by Carlson et al.[23] PALMS algorithms had mean accuracies ≥85% (i.e., mean bias ≤15%) and Intraclass Correlation Coefficients ≥.80 for classifying minutes/day in each trip mode. PALMS overestimated minutes/day in vehicle by 14.7% and bicycling by 7.2%, and underestimated minutes/day of walking by 11.4% as compared to SenseCam.

For inclusion in the present analyses, the participant must have worn the GPS device for ≥2 days during which the GPS showed engaging in ≥1trip/day (of any speed). There was no way to know whether days with no trips indicated the participant was home this entire day or traveled while leaving the GPS device at home, so these days were removed from the dataset. This resulted in removal of 197 participants (764 days). Participant characteristics (age, gender, ethnicity and MVPA) did not differ between the full study sample and the subsample reported in this paper, with the exception that 43.5% of the subsample in this paper resided in the Baltimore, MD region whereas 50.0% of the full sample resided in the Baltimore, MD region. Participant-level average minutes/day variables were calculated by summing the number of minutes in each mode and dividing by the number of days of observation. An active travel mode share variable was created by taking (daily walking + bicycling minutes) / total daily travel time * 100.

Total physical activity and sedentary time. Participants wore an Actigraph accelerometer on a belt at their left iliac crest with acceleration recorded at 30-second epochs. Several models of the Actigraph were used: 7164 (85.2%), 71256 (5.1%), GT1M (7.2%) and GT3X (2.5%). Device model was not associated with MVPA and had a very small correlation (r=.06) with sedentary time in this study. MVPA was scored using the Freedson 4-MET age-based cut points,[24] and sedentary time was scored using the commonly used cut point of <100 counts per minute,[25,26] both of which have been shown to have excellent classification accuracy.[27] The cut points, which apply to 60-second epochs, were divided by 2 to account for the use of 30-second epochs in the present study. Days were removed from the present analyses if the participant did not wear the accelerometer for ≥10 valid hours, resulting in removal of an average of 1.4 days per person. Groups of >60 sequential 30-second epochs with no movement (i.e., count=0) were considered non-wear. Minutes/day of MVPA and minutes/day of sedentary time were analyzed.

Objective home neighborhood built environments. From each region, data from the county tax assessor, regional land use at the parcel level, and street networks were integrated into a Geographic Information Systems (GIS) to derive built environment features within a 1-km street network buffer (i.e., service area) around each participant's home. Net residential density (housing units per residential parcel), intersection density (intersections per square km), retail density (number of retail parcels; e.g., shopper centers, stores, banks), and entertainment density (number of entertainment parcels [non physical activity-related]; e.g., theaters, museums, social clubs) were calculated from data available from the included jurisdictions. Because it is the overall pattern of neighborhood attributes, often referred to as "neighborhood walkability", that is often associated with physical activity and health outcomes (e.g.,[12–15,19]), we also investigated the study design factor which classified each block group as having "high" or "low" walkability. The components of walkability for the present study included net residential density, intersection density, land use mix, and retail floor area ratio. The high vs. low walkability study design factor is described above in our "Participants and Procedures" Section, and the walkability classification is described in more detail in elsewhere.[19,28] This walkability index has been validated[18] and shown to be related to health outcomes in several studies.[29,30]

Demographics. Adolescents' age, gender, and ethnicity (non-Hispanic white vs. other), were collected in an adolescent survey, and parents' highest level of education (college degree vs. other), marital status (married/living together vs. other), and number of licensed drivers in the household were collected in a parent survey.

Analyses

The distributions and mean (SD) minutes/day of the trip variables were assessed at the day level as well as on averages across days at the participant level. To investigate the proportion of walking that registered as MVPA, the number of walking epochs that met age-based criteria for MVPA was divided by the total number of walking epochs. All models were three-level mixed-effects random intercept linear regression models, with days nested within participants nested within block groups. First, we tested whether minutes/day in each trip mode (dependent variables) differed between weekdays and weekends. Next, we tested the relation of walking and in vehicle minutes/day to the dependent variables total MVPA and sedentary minutes/day in separate models, as well as the association between walking time and vehicle time. Bicycling time was not compared to MVPA and sedentary time because accelerometers do not track bicycling well. Finally, we tested the relations of the three walkability components (initial models) and walkability index (separate models) to the dependent variables walking, bicycling, and vehicle minutes/day as well as percent of mode share in active travel. Since the trip variables, particularly walking and bicycling, had a high number of zeros (i.e., 0 minutes/day), the negative binomial distribution was used to estimate models using trip variables as the dependent variable. Regression coefficients from negative binomial models can be interpreted as the percent increase/decrease in the dependent variable associated with a 1 unit increase in the independent variable. To make the regression coefficients for residential density, intersection density, and retail density more meaningful, residential density was divided by 10, intersection density by 20, and retail density by 20. These denominators were approximately the standard deviations for these measures, and the regression coefficients for these variables can be interpreted as the percent increase/decrease in the dependent variable associated with a 1 standard deviation increase in the independent variable. All models were adjusted for participant age, gender, and ethnicity, parent marital status and education, region, number of vehicles in household, neighborhood income (high vs. low), accelerometer model, and number of days wearing the devices. Models with sedentary time were adjusted for accelerometer wear time because wear time varied across days and participants, and those who wore the device longer had more opportunities to be sedentary. The linear mixed-effects models were fitted using the GENLINMIXED command in SPSS version 21. Intraclass correlation coefficients representing the proportion of variance in the outcomes attributable to between block (rather than between person) effects were calculated as intercept / (residual + intercept) from the covariance estimates from empty models.

RESULTS

A total of 690 adolescents from 380 census block groups had at least 2 valid days of wearing both devices, with 2987 total days and an mean of 5.3 (SD=2.0) days/participant. Participant characteristics of this study subsample were similar to those within the overall TEAN study. Mean age of participants was 14.1 (SD=1.5) years, 50.5% were female, and 68.6% were White non-Hispanic. Sixty-four percent of parents had a college degree and 84% were married or living with a partner (see Table 1). Families had an average of 2. 5 (SD=1.0) vehicles in the household. Participants engaged in an average of 33.8 (SD=20.5) minutes/day of MVPA, and 65% of the walking time identified by GPS in the present sample met criteria for MVPA based on accelerometer counts. Table 2 presents day- and participant-level descriptive characteristics for the GPS-derived trip variables. Walking occurred on 33.1% of the days observed, active travel occurred on 43.1% of the days observed, and vehicle time occurred on 91% of the days observed. Median walking minutes/day was 0 and median vehicle minutes/day was 21. Walking time did not differ significantly between weekends and week days (exponentiated B = 1.31; 95% CI = 0.88, 1.97; weekends vs. week days). There was a trend ($p < .1$) suggesting that the percent of mode share in active travel was lower on weekends as compared to week days (exponentiated B = 0.76; 95% CI = 0.54, 1.05; weekends vs. week days). Vehicle time was 38% higher on weekends as compared to week days (exponentiated B = 1.38; 95% CI = 1.16, 1.64; weekends vs. week days), and bicycle time was 40% higher on weekends as compared to week days (exponentiated B = 1.40; 95% CI = 1.30, 1.52; weekends vs. week days).

The associations among walking time, vehicle time, physical activity, and sedentary times are presented in Table 3. For every 1 minute/day of walking, participants had 0.94 (95% CI = 0.83, 1.04) more minutes/day of MVPA and 0.31 (95% CI = 0.24, 0.38) fewer minutes/day of sedentary time. For every 1 minute/day of vehicle time, participants had 0.02 (95% CI = 0, 0.05) more minutes/day of MVPA and 1.07 (95% CI = 0.81, 1.33) fewer minutes/day of sedentary time. Walking and vehicle time were uncorrelated.

Table 4 presents the relations of the home neighborhood built environment variables to walking, bicycling and vehicle time as well as percent of mode share in active travel. Eighteen percent of the variance in walking, 4.1% of the variance in bicycling, and 22.5% of the variance in vehicle time was between block groups. Older adolescents and those with fewer vehicles in their household spent more time walking than their counterparts. Older participants, boys, and those living in the Seattle region spent more time bicycling than their counterparts. Similarly, older participants, boys, and those with fewer vehicles in their household spent more of the mode share in active travel as compared to their counterparts. Older participants and girls spent more time in a vehicle than their counterparts.

For every 10 more housing units per parcel in the 1km participant buffer, walking increased by 40% (95% CI = 2%, 92%) and percent of mode share in active travel increased by 64% (95% CI = 15%, 134%). For every 20 more intersections per square km, walking increased by 22% (95% CI = 4%, 43%), bicycling by 30% (95% CI = 6%, 60%), and percent of mode share in active travel by 34% (95% CI = 13%, 59%). Vehicle time decreased by 7% (95% CI = 2%, 22%) for every 20 more intersections per square km. Walking time was lower in neighborhoods with greater entertainment density.

Neighborhood walkability was associated with each of the four transportation outcome variables. Participants living in high-walkable neighborhoods had 92% (95% CI = 38%, 165%) more walking, 97% (95% CI = 30%, 198%) more bicycling time, 125% (95% CI = 59%, 218%) more of their mode share in active travel, and 13% (95% CI = 2%, 22%) less vehicle time compared to those in low-walkable neighborhoods.

DISCUSSION

Walking and bicycling for transportation among adolescents was low, with walking occurring on only 33.1% of days and bicycling on 15.7% of days. Our finding that a minute of walking was associated with approximately 1 additional minute of total MVPA suggests that interventions to increase the current low rates of walking for transport in adolescents have potential for improving overall physical activity. The finding that participants in high-walkable neighborhoods had 92% more walking, 97% more bicycling, and 13% less vehicle time suggests the potential for built environment interventions to substantially increase active transport and decrease vehicle time.

Intersection density was the most consistent individual environmental component associated with each of the transport outcomes. Furthermore, residential density was a correlate of walking and percent of mode share in active travel. These factors have been relatively consistent correlates of adolescents' active travel in previous studies.[12–14] It is likely that a large proportion of adolescents' active travel is to and from school, and our finding that the percent of mode share in active travel was higher on week days as compared to weekends (p trend) weakly supports this inference. Thus, the aforementioned findings are not surprising given that distance to school has been found to be correlated with residential and intersection density.[31,32] Greater residential and intersection density also likely correspond to shorter distances to friends' homes, another likely destination of adolescents' active travel. These findings suggest that poor macro-level built environment characteristics are important barriers to walking and an inhibitor of physical activity in adolescents. Built environments, although perhaps slow to change, have promising potential for modification through land use and transportation policies.[33]

High vs. low walkability was positively associated with walking, bicycling, and percent of mode share in active travel, and negatively associated with vehicle time. These findings are in agreement with those from transportation research studies.[34,35] The present study specifically targeted high- and low-walkable neighborhoods to maximize variability in neighborhood environment characteristics. A substantial finding was that adolescents had almost twice as much walking and bicycling in high- vs. low- walkable neighborhoods. While it is likely not feasible to rapidly transform low-walkable neighborhoods into high-walkable neighborhoods, present findings from the individual environment component models suggest that even small improvements in these factors, such as additional pedestrian/bicycle paths in low-connectivity areas, could contribute to meaningful increases in active travel.

It was unexpected that greater entertainment density was associated with lower rates of walking. Retail density was unassociated with all of the travel mode variables. Though the individual built environment variables had varying, sometimes unexpected, associations with active travel, the findings for the overall walkability index were strong and consistent across outcomes. Adolescents living in high-walkable neighborhoods were much more likely to use active travel modes and took fewer motorized trips. Because walkability represents a combination of variables expected to be favorable for active travel, it is expected that a coherent pattern of variables would be more consistently related to travel-related outcomes than individual variables. Reviews indicate that walkability is one of the most consistent correlates of active transport for both youth and adults,[36] so present results build on previous studies by using objective measures of transport modes.

Although only 65% of walking minutes (according to GPS) had accelerometer counts that met MVPA cut points, a 1 minute increase in walking was associated with approximately a 1 minute increase in total physical activity. These findings suggest that walking for transportation has potential for increasing overall physical activity in youth. The low rates of walking in the present sample suggest strong need for interventions, likely targeting environments and individuals, because even in high-walkable neighborhoods, walking rates were low. Increasing walking for transportation can be expected to contribute to overall physical activity, but further studies are needed to determine whether this close association applies at higher levels of walking for transportation.

The 2009 US National Household Transportation Survey found that among adolescents aged 11–15 years, 75% had any walking or bicycling in the past week,[37] similar to findings in the present study that 77% of participants had any walking or bicycling during the assessment period. Mean walking and bicycling time for adolescents in the National Household Transportation Survey was 14 minutes/day, which is also alarmingly low but higher than the mean walking and bicycling time of 5 minutes/day found in the present study.[37] (Note that medians rather than means were presented in the results section because walking and bicycling time had skewed distributions, whereas mean walking and bicycling time are presented here for comparison). There are likely multiple reasons for these differences. It is possible that adolescents' active travel time is overestimated in the National Household Transportation Survey, partly because adults provided proxy reports. A previous study showed good validity for the GPS trip-processing methods used in the present study, but suggested that these methods may underestimate daily walking time by approximately 10%.[23] In the present study 30-second epochs were eliminated from walking trips if the accelerometer values were <500 counts/epoch. This was done to eliminate trip pauses, but it is possible that trip pauses are included as walking time in adult-proxy reports of adolescents' active travel in the National Household Transportation Survey. It is also important to note that the present sample was not a nationally representative sample as was the National Household Transportation Survey sample.

It is not clear why vehicle time was related to more physical activity and less sedentary time. It is possible that some adolescents' were being driven to locations to perform physical activity, such as sports fields. It is also likely that some of the vehicle time involved public transportation, and previous studies have found active transportation users were significantly more active than non-users.[38,39] It is important to consider that vehicle time is estimated to be 20–100% higher in adults than youth, so vehicle time is likely a stronger contributor of sedentary time in adults.[9,40] It is notable that the present sample was too young to have a driver's license, and time in vehicles increases among adolescents of driving age.[9]

Strengths and Limitations

The present study applied recently validated algorithms to objectively assess daily walking, bicycling and vehicle time in adolescents using GPS. Although GPS provided an objective assessment of trips and trip mode, misestimation may still exist (e.g., missed walking trips, misclassification of walking/running as bicycling) due to the limits of the data. However, the classification algorithms used in the present study performed well in a validation study and are open source[21,23] so they can be evaluated and improved upon by other investigators. Since waist-worn accelerometers do not adequately capture MVPA while bicycling, we were not able to assess the contribution of bicycling to total physical activity. It is important to note that only 65% of walking time (assessed via GPS) was classified as MVPA by the accelerometer. This suggests that some walking does not meet intensity thresholds for classification as MVPA, and/or that accelerometer cut points are not adequate for assessing walking. The use of relatively high 4 MET (metabolic equivalents) cut points is less sensitive than lower cut points, highlighting a problem caused by the lack of consensus in scoring of accelerometer data.[41] Advances in accelerometer data processing, such as pattern recognition, may provide more insight into the walking—total physical activity association. Unfortunately, we were not able to determine if the participant was wearing the GPS device on days the GPS showed no trips. The removal of these days may have biased the findings presented in Tables 3 and 4 and made it more likely to detect an association between time in trips and physical activity. However, the difference in MVPA for days with trips vs. days with no trips (i.e., days when the GPS may or may not have been worn) was small (+4 minutes/day, 12% difference). The reasons walking trips contributed to total physical activity could not be determined in the present study. The walking itself could be a primary contributor, or perhaps adolescents sometimes walked to places to do recreational physical activity. Future studies should examine the mechanisms by which active travel is related to total physical activity.

Assessing trips at the day, as well as participant level, allowed for greater understanding of adolescents' travel patterns. Combining GPS and accelerometer measures improved understanding of the contribution of travel patterns to total physical activity. The present study focused on macro-level walkability characteristics because these have been among the strongest environmental correlates of adolescents' physical activity in previous studies,[12] but future studies should investigate other environmental and psychosocial factors in relation to adolescents' objectively measured walking, bicycling and vehicle time (e.g., sidewalks, bike paths, social support for active travel). Although associations between the home neighborhood environment variables and travel mode were documented, there was no assessment of whether the trips (e.g., walking, bicycling) were occurring in the home neighborhood, so it is possible these trips were occurring elsewhere. Future research should match trips and physical activity to the characteristics of the environments in which the behaviors occur. It is important to note that the present study was a cross-sectional observational study, so causal inferences cannot be made.

Conclusions

Recently validated algorithms to measure walking, bicycling and vehicle time from GPS revealed low rates of walking and bicycling for transportation among adolescents in two regions of the US. More walking corresponded to more total physical activity at almost a 1:1 rate, suggesting that increasing walking from its current low level can efficiently improve overall physical activity. Walking and bicycling were positively associated with, and vehicle time was negatively associated with, home neighborhood walkability, particularly intersection density (for all three modes) and residential density (for walking) components, providing convergent validity for these GPS-derived trip variables. The present findings suggest potential for increasing adolescents' physical activity through walking for transportation, and creating more physical activity-supportive neighborhood environments could be effective in achieving this goal. However, since walking rates were low even in high-walkable neighborhoods, individual-level interventions are likely also needed.

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Table 1

Characteristics of study sample

Number of participants	690
Number of block groups	380
Age, Mean (SD)	14.1 (1.5)
Female, %	50.5
White non-Hispanic, %	68.6
Parent with college degree, %	64.0
Parent married or living with partner, %	84.0
Number of vehicles in household, Mean (SD)	2.5 (1.0)
Device wear days, Mean (SD)	5.3 (2.0)
Accelerometer wear minutes/day, Mean (SD)	829.2 (79.1)
MVPA minutes/day, Mean (SD)	33.8 (20.5)
Sedentary minutes/day, Mean (SD)	542.4 (90.4)
Housing units per parcel, Mean (SD)	6.2 (9.5)
Intersections per square kilometer, Mean (SD)	74.0 (21.9)
Number of retail parcels, Mean (SD)	10.5 (21.1)
Number of entertainment parcels, Mean (SD)	0.1 (0.6)

Abbreviations: MVPA = moderate to vigorous physical activity; SD = standard deviation

Table 2

Descriptive statistics for participant-level transportation variables

	Days	Participants
N	2987	690
Walking trips		
Number (percent) with any walking	990 (33.1%)	427 (61.9%)
Median (IQR) walking minutes/day	0 (0, 3.5)	1.0 (0, 3.6)
Median (IQR) walking minutes/day for those with any walking	6.0 (3.5, 14.0)	2.8 (1.2, 6.3)
Bicycling trips		
Number (percent) with any bicycling	470 (15.7%)	308 (44.6)
Median (IQR) bicycling minutes/day	0 (0, 0)	0 (0, 1.2)
Median (IQR) bicycling minutes/day for those with any bicycling	4.5 (2.5, 8.0)	1.4 (0.6, 3.1)
Vehicle trips		
Number (percent) with any vehicle time	2717 (91.0%)	680 (98.6)
Median (IQR) vehicle minutes/day	21.0 (8.5, 43.0)	23.9 (14.0, 39.4)
Median (IQR) vehicle minutes/day for those with any vehicle time	23.5 (11.5, 46.0)	24.3 (14.5, 40.0)
Active travel mode share		
Number (percent) with any walking or bicycling	1288 (43.1)	520 (76.8)
Median (IQR) percent of travel time active[a]	0 (0, 22.4)	8.6 (0.9, 29.4)
Median (IQR) percent of travel time active for those with any active travel time[a]	29.6 (11.8, 75.9)	17.6 (5.8, 35.9)

Abbreviations: IQR = interquartile range

[a]Calculated at the day level as (walking minutes + bicycling minutes)/total travel minutes * 100

Table 3

Associations among walking time, vehicle time, physical activity, and sedentary time in adolescents (N = 2987 days from 690 participants)[a]

	MVPA, minutes/day	Sedentary, minutes/day[b]	Vehicle time, minutes/day
Walking time, minutes/day B (95% CI)	0.94 (0.83, 1.04)	−0.31 (−0.38, −0.24)	0.05 (−0.09, 0.18)
Vehicle time, minutes/day B (95% CI)	0.02 (0, 0.05)	−1.07 (−1.33, −0.81)	-

[a]Adjusted for participant age, gender, region, and ethnicity, parent education, parent marital status, number of vehicles in household, neighborhood income, accelerometer model and number of device wear days

[b]Additionally adjusted for accelerometer wear time (hours/day)

Abbreviations: B = unstandardized regression coefficient; CI = confidence interval; MVPA = moderate to vigorous physical activity

Table 4

Relations of built environment characteristics to walking, biking and vehicle time in adolescents (N = 2987 days from 690 participants)[a]

	Walking time, negative binomial		Bicycle time, negative binomial		Vehicle time, negative binomial		% of mode share active, negative binomial	
	% change in DV (95% CI)	***P***	**% change in DV (95% CI)**	***P***	**% change in DV (95% CI)**	***P***	**% change in DV (95% CI)**	***P***
Covariates								
Age (years)	1.15 (1.03, 1.28)	.013	1.15 (1.00, 1.33)	.045	1.04 (1.00, 1.08)	.038	1.11 (0.98, 1.25)	.086
Girls (vs. boys)	0.81 (0.59, 1.12)	.200	0.47 (0.31, 0.71)	<.001	1.11 (0.99, 1.24)	.072	0.63 (0.45, 0.89)	.009
White non-Hispanics (vs. other)	0.97 (0.68, 1.37)	.843	0.75 (0.49, 1.17)	.210	0.99 (0.87, 1.11)	.827	0.87 (0.60, 1.26)	.461
Baltimore (vs. Seattle)	0.79 (0.56, 1.10)	.166	0.56 (0.36, 0.86)	.008	1.06 (0.95, 1.19)	.293	0.74 (0.52, 1.06)	.101
Parent college degree (y vs. n)	1.01 (0.72, 1.43)	.945	0.90 (0.58, 1.39)	.630	1.06 (0.94, 1.19)	.356	0.79 (0.55, 1.14)	.209
Parent married (y vs. n)	0.64 (0.39, 1.03)	.065	0.74 (0.40, 1.36)	.330	0.94 (0.80, 1.13)	.549	0.79 (0.47, 1.32)	.361
Vehicles in household (number)	0.77 (0.65, 0.92)	.004	0.84 (0.68, 1.06)	.137	1.04 (0.98, 1.11)	.180	0.80 (0.66, 0.96)	.019
Neighborhood income (high vs. low)	1.10 (0.78, 1.54)	.598	0.78 (0.50, 1.20)	.255	0.98 (0.87, 1.10)	.675	1.13 (0.78, 1.62)	.518
Built environment components								
Residential density / 10 (housing units per parcel / 10)	1.40 (1.02, 1.92)	.040	1.06 (0.72, 1.58)	.764	0.93 (0.82, 1.04)	.205	1.64 (1.15, 2.34)	.007
Intersection density / 20 (intersections per square kilometer / 20)	1.22 (1.04, 1.43)	.012	1.30 (1.06, 1.60)	.011	0.93 (0.86, 1.02)	.004	1.34 (1.13, 1.59)	.001
Retail density / 20 (number of retail parcels / 20)	0.94 (0.73, 1.20)	.621	1.03 (0.75, 1.41)	.853	0.94 (0.86, 1.02)	.169	1.02 (0.79, 1.33)	.868
Entertainment density (number of entertainment parcels)	0.58 (0.37, 0.64)	.016	1.17 (0.67, 2.02)	.585	1.15 (0.98, 1.34)	.092	0.64 (0.40, 1.02)	.063
Walkability[b]								
High walkability (vs. low)	1.92 (1.38, 2.65)	<.001	1.97 (1.30, 2.98)	.001	0.87 (0.78, 0.98)	.023	2.25 (1.59, 3.18)	<.001

[a]Adjusted for participant age, gender, region, and ethnicity, parent education, parent marital status, number of vehicles in household, neighborhood income, accelerometer model and number of device wear days

[b]The walkability index was entered in a separate model than the individual walkability components.

Abbreviations: CI = confidence interval; OR = odds ratio; P = p value; DV = dependent variable.