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Neighborhood built environment and socioeconomic status in relation to physical activity, sedentary behavior, and weight status of adolescents

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Contributors' Statement Page

James F. Sallis conceptualized the study, obtained funding, participated in study design, drafted sections, critically reviewed and revised the manuscript, and approved the final manuscript as submitted.

Terry L. Conway conceptualized the study, participated in study design, conducted analyses, contributed to interpretation, drafted sections, critically reviewed and revised the manuscript, and approved the final manuscript as submitted.

Kelli L. Cain conceptualized and designed the study, participated in data management and analyses, drafted parts of the manuscript, critically reviewed and revised the manuscript, and finalized the approved manuscript as submitted.

Jordan A. Carlson contributed to data and analyses and interpretation, drafted parts of the manuscript, critically reviewed and revised the manuscript, and finalized the approved manuscript as submitted.

Lawrence D. Frank participated in study design and results interpretation, created the GIS measures, critically reviewed and approved the final manuscript as submitted.

Jacqueline Kerr participated in study design, results interpretation, critically reviewed and approved the final manuscript as submitted.

Karen Glanz participated in study design, results interpretation, critically reviewed and approved the final manuscript as submitted.

James E. Chapman contributed to creating the GIS variables, conducted some analyses, critically reviewed and revised the manuscript, and finalized the approved manuscript as submitted.

Brian E. Saelens participated in study design, results interpretation, critically reviewed and approved the final manuscript as submitted.

Urban Design for Health

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Abstract

Introduction—The study examined the association of neighborhood walkability to multiple activity-related outcomes and BMI among adolescents and evaluated socioeconomic status as an effect modifier.

Method—Cross-sectional study, with adolescents recruited from neighborhoods that met criteria for a 2 × 2 matrix defined by high/low GIS-defined walkability and high/low median income. Adolescents aged 12-16 years (n=928) were recruited from selected neighborhoods in Maryland and King County, Washington regions in 2009-2011. There were 50.4% girls, and 66.3% were non-Hispanic white, with no medical restrictions on physical activity (PA) or diets. Total PA and sedentary time was assessed by 7 days of accelerometer monitoring. Adolescents self-reported active transport, time spent on 6 sedentary behaviors, and height and weight, used to compute BMI percentiles. Mixed model linear and logistic regressions examined outcomes for association with walkability and income, adjusting for demographic covariates and clustering within block groups.

Results—Walkability was positively and significantly related to objectively-measured PA (p<.001) and more frequent walking for transportation (p<.001). Total self-reported total sedentary time (p=.048) and TV time (p<.007) were negatively related to walkability. Time in vehicles was negatively related to walkability only among higher-income adolescents.

Conclusions—Neighborhood walkability was strongly and consistently associated with adolescents' objectively-assessed total physical activity and reported active transportation. A novel finding was that adolescents living in walkable neighborhoods reported less television time and less time in vehicles. Most results were similar across income categories. Results strengthen the rationale for recommendations to improve walkability.

Keywords

exercise; sitting; walkability; obesity; television; health disparities

Introduction

Improvements in built environments are recommended to improve physical activity and reduce risk of obesity by numerous authoritative organizations.[1–6] Exposure to built environments can affect entire populations over long time periods, and the design of neighborhoods has been related to several important health outcomes and behaviors.[7] The most-studied behavior has been physical activity. Walkable community designs are believed to encourage walking and bicycling to destinations and contribute to total physical activity.[3,8] Evidence linking walkability with physical activity is less consistent for youth than for adults.[9]

Sedentary time, or sitting behaviors, are of interest because excessive sitting is a risk factor for metabolic disorders and weight gain, with most studies of youth based on television viewing.[10] A few studies of adults examined hypotheses that neighborhood environments with few opportunities for physical activity may lead residents to do more sedentary recreation, such as television viewing and computer games, but results have been inconsistent.[11] Many studies demonstrate that adult and youth residents of low-walkable, automobile-oriented neighborhoods spend more time in cars, a necessarily sedentary activity.[12,13] One study reported adolescents living in mixed-use neighborhoods spent less time watching television.[14]

Increased physical activity is recommended as a youth obesity prevention strategy.[1,15] Though overall sedentary time has not been consistently related to youth weight status,[16] television viewing time is related to youth obesity, possibly due to effects on eating behaviors.[15] Studies of the relation of neighborhood environment attributes to weight status in adolescents have been inconsistent.[17]

There is growing evidence of socioeconomic status (SES) disparities in built environment variables[18,19], so it useful to understand whether SES variables are effect modifiers between built environments and health-related outcomes. The present study examined the association of walkability to physical activity, sedentary time, and body mass index (BMI) among adolescents and examined SES as an effect modifier.

Methods

Study Design

Data were from the TEAN (Teen Environment And Neighborhood) study conducted in the Baltimore, Maryland-Washington, DC and Seattle-King County, Washington metropolitan areas 2009-2011. A cross-sectional 2×2 design was used to select census block groups of higher-versus lower-walkability and higher- versus lower-median household income, similar to prior studies.[20,21]

Block group Selection for Participant Recruitment

Census block group selection procedures were similar to those of a previous study.[20,22] Median household income of census block groups was identified from the 2000 census. In each region, median household incomes of block groups were deciled, then categorized by median split to represent lower or higher income levels. Walkability for each block group was calculated using GIS (Geographic Information Systems; King County data from 2006 and Maryland data from 2003) measures of net residential density, street connectivity, retail floor area ratio, and land use mix, as described previously.[20] These variables were normalized within each region, and z-scores of items were summed to create the walkability index for each block group. In each region, block group walkability scores were deciled and categorized by median split to represent lower or higher walkability. The walkability and income categories for each block group were crossed (low/high walkability by low/high income) to place each block group into one of the study design quadrants (lower-walkability/lower-income, lower-walkability/higher-income, higher-walkability/lower-income, higher-walkability/higher-income). Participants were recruited from eligible block groups in each quadrant. Table 1 presents walkability and income characteristics of each study design quadrant, separately for the two regions, along with the number of census block groups. The table documents the clear differences in walkability and income that were achieved by the sampling strategy.

Participant Recruitment

Households in eligible block groups with adolescents aged 12-16 were identified from a list purchased from a marketing company and randomly selected to be contacted. Potential participants were sent study information by mail and called via telephone to attempt recruitment. Recruitment was conducted simultaneously in all quadrants to avoid seasonal bias and was conducted only during the school year. Adolescents were ineligible if they had a condition affecting their physical activity (e.g., physical disability), dietary habits that significantly limited their intake (e.g., eating disorder), or inability to participate (e.g., developmental disability). Participating youth completed assent forms, and a parent provided consent. The Institutional Review Boards of participating universities approved this study. A $40 incentive was provided for participating in the study.

Measurement

Details about all outcome measures are provided in Table 2. This section reports on the procedures used to collect data and create variables used in analyses.

Physical activity and sedentary behavior

Multiple measures were used to reflect the range of physical activity options, including active transportation, leisure activity overall and in the neighborhood. Overall and specific sedentary behaviors were assessed. Both accelerometer-based and self-report measures were collected for physical activity and sedentary behavior.

As shown in Table 2, almost all measures had evidence of reliability and/or validity. Adolescents had the option of completing surveys online or with mailed hard copies. Actigraph accelerometers were mailed to participants with detailed instructions for wearing the device for 7 days. Participants were asked to rewear the meter if fewer than 5 valid days of data were received. At least 3 valid wearing days were required for inclusion in analyses. Thirty percent of participants were asked to rewear the device, and data from both times were combined to obtain at least 3 valid days. The average time between first and second accelerometer wearing start dates was 46 days. Due to lack of consensus on preferred cut-points for moderate-to-vigorous physical activity (MVPA), analyses were conducted using higher[25] and lower 3-MET[24] intensity cut-points. Sedentary time was scored with the commonly used cut point of ≤ 100 counts per minute.[24–26]

Body mass index (BMI)

Both adolescents and parents were provided detailed instructions on measuring weight and height. Adolescent self-report of height and weight has evidence of good validity.[34,35] CDC growth charts were used to calculate age- and gender-adjusted BMI percentile as well as BMI weight-status category, with participants ≥ the 80th BMI percentile classified as overweight and those ≥ the 95th percentile classified as obese.

Covariates

Potential adolescent covariates included adolescent's self-reported age, gender, race/ethnicity (recoded as white/non-Hispanic or non-white/Hispanic), days per week living at primary address, attended school outside the home versus home-schooled, work status (volunteer or paid job versus no work outside the home), and driver's license (yes/no). Potential *household covariates* included parent-reported number of children under 18 years old in the household, number of motor vehicles per licensed driver, years living at current address, and walkability-related reasons for moving to their current neighborhood (3-item scale indicating parent's average agreement with statements related to ease of walking in the neighborhood and closeness to shops, services, and transportation).[22] Study site (Seattle/King County or Maryland/Washington, DC regions) was examined as a covariate. The Actigraph accelerometer models used produce relatively comparable results for MVPA[36] but less comparable results for sedentary time.[37,38] Therefore, a code for type of Actigraph model worn was entered as a categorical covariate in all analyses involving accelerometers.

Statistical Analysis

The primary exposure variables were high/low neighborhood walkability and high/low neighborhood income. The main aim was to determine whether neighborhood income was an effect modifier,[39] but the main effect of both walkability and neighborhood income were also of interest. For each outcome, the full model (two main effects, their cross-product, all covariates) was initially tested to determine whether there was a walkability-by-income modifier effect. To minimize type 2 error, the effect-modifier cross-product term was retained if $p < .10$. This term was removed if $p > .10$, and the model re-run to assess walkability and income main effects. The covariates were examined using backwards elimination procedures, retaining covariates in the final model if $p < .15$.

Separate mixed effects regression models (using SPSS MIXED) were fit for all continuous dependent variables, and generalized linear mixed models (using SPSS GENLINMIXED, binomial distribution and logit link function) were fit for the dichotomous obese and overweight-or-obesity outcomes. All models were adjusted for clustering of participants nested within census block groups by entering census block group as a random effect.

Results

Participant Characteristics and Representativeness

Participants were 928 adolescents; n = 443 in Seattle/King County, WA and n = 445 in the Baltimore/Maryland region. There were 468 (50.4%) girls and 460 (49.6%) boys; 66.3% were non-Hispanic white and 33.7% were nonwhite or Hispanic. The average adolescent participant's age was 14.1 (SD = 1.4) years old, with a range from 12-17 years (upper age for recruitment was 16 years old; however, 7 teens turned 17 between recruitment and data collection); 5.9% of adolescents had a driver's license, 4.2% were home-schooled, and 31.0% reported working/volunteering outside the home. Parents/caregivers reported the highest education for any adult in the household was a college degree (74%), they had lived at the current address for an average of 12.6 (SD = 7.0) years, had 2.0 (SD = 1.1) children under the age of 18 living in the household, and had 1.1 (SD = 0.38) motor vehicles per licensed driver in the household.

Overall participation rate (i.e., returned surveys divided by eligible contacts) was 36% and did not vary by quadrant. Comparisons of participants' household demographics with census data indicated the study sample had higher education and household income compared to residents of the 447 census block groups in which participants lived. Regarding race/ethnicity, the study sample was comparable to census data for adolescent participants, with 34% being non-White or Hispanic versus 37% of adolescents in the census block groups from which participants were recruited.

Neighborhood Walkability and Income Effects

Differences on outcomes among participants living in neighborhoods in the higher- vs. lower-walkable and higher- vs. lower-income quadrants are shown in Table 3.

Physical activity

Accelerometer measures—Adolescents' average daily MVPA was higher in walkable neighborhoods for both accelerometer cutpoints examined, with the Evenson-cutpoint scores also showing higher MVPA for youth in higher income neighborhoods. Youth living in areas with higher-walkability accumulated approximately 4.5 more minutes of objectively measured MVPA per day (4.7 min/day for 3-METs; 4.9 min/day for Evenson cutpoints) than youth living in lower-walkability areas, averaged across income groups.

Physical activity: Survey measures—Adolescents' reported engagement in active transportation (walking, biking, skateboarding) to non-school places was almost 23% higher for those living in higher-walkable compared to lower-walkable areas ($p<.001$). Adolescents living in higher-income neighborhoods participated in more sports teams/physical activity classes outside of school than those living in lower-income areas ($p=.007$). A walkability-by-income effect indicated a trend for more frequent active transportation to school among adolescents living in higher-walkable neighborhoods (just over 2 trips per week) than in lower-walkable neighborhoods, with no differences by neighborhood income; however, in lower-walkable neighborhoods there were about twice as many trips per week in lower-income (1.53) than in higher-income (0.73) neighborhoods ($p=.067$).

Sedentary time and activities—The accelerometer measure of sedentary minutes per day showed no walkability or income main effects or income-related effect modification. However, the self-reported sum of six types of sedentary activities on typical school days (non-school time) had significant effects for both walkability ($p=.048$) and income ($p=.017$). Adolescents living in higher-walkable areas reported approximately 26 fewer minutes per day across the six sedentary activities compared to those living in lower-walkable areas, and about 31 fewer minutes per week in higher-relative to lower-income areas. The only specific sedentary behavior with significant effects for both walkability ($p=.001$) and income ($p<.001$) was minutes per school day watching television, videos, or DVDs. Adolescents living in higher-walkable areas reported less time (average of 15.6 fewer minutes per school day) watching television, videos, or DVDs compared to those living in lower-walkable areas, and averaged 18.4 fewer minutes per school day in higher-relative to lower-income areas. Two domain-specific sedentary outcomes with significant neighborhood income main effects were playing sedentary computer/video games (p=.020) and doing homework (p=.012). Compared to adolescents living in lower-income neighborhoods, those in higher-income neighborhoods averaged 10.2 *fewer* minutes per school day playing computer/video games but 12.0 *more* minutes per school day doing sedentary homework tasks. A trend for a walkability-by-income effect modificationindicated adolescents living in higher-walkable/ higher-income neighborhoods spent fewer minutes per school day (44.8 min) riding in a vehicle compared to those in the other three quadrants (average of 53.2 min) (p=.092).

BMI-related measures—BMI did not differ by walkability, but participants from lower-income neighborhoods had higher BMI-percentiles (p=.042) and were more likely to be overweight or obese (p=.052) than those living in higher-income areas. A trend for a walkability-by-income effect modification indicated that lower-walkable/lower-income neighborhoods had the *highest* percent of obese adolescents (16.7%) and lower-walkable/ higher-income neighborhoods had the *lowest* percent of obese adolescents (8.8%) (p=.066).

Discussion

Greater home neighborhood walkability was associated as expected with adolescents having higher objectively-measured total MVPA, as well as more active transport to non-school destinations compared to adolescents living in low walkable neighborhoods. Walkability was also associated with less reported out-of-school sedentary time and less time watching TV/ videos/DVDs, but not with objectively-measured total sedentary time. These findings applied similarly across income levels. For a few outcomes there was evidence that neighborhood income was an effect modifier of walkability. For the sedentary behavior of time in cars a walkability effect was found only among those in higher-income neighborhoods. There was a trend for effect modification related to obesity status, suggesting those in low-walkable, low-income neighborhoods had the highest obesity rates. Though not consistent across all measures, the pattern of results supports a conclusion that living in low-walkable neighborhoods is a risk factor for lower adolescent physical activity and higher sedentary time, especially television and DVD viewing. Present results add evidence to justify the numerous recommendations to improve walkability of neighborhood environments.[1–6]

The effect size for walkability was a difference in total objectively measured MVPA of about 4.5 min/day or 31 min/week. This represents a walkability effect of 10-15% on adolescent physical activity, which could be considered an important population effect. It may be useful to compare present results with adolescents to a study of similar design with adults in the same regions. The high/low walkability difference of 4.5 min/day for adolescents was somewhat less than the walkability effect size of 5-7 min/day found in the adult study.[22] Prior studies[9] supported associations of specific domains of physical activity with neighborhood walkability, mainly related to active transportation. Present results were consistent with this interpretation, because neighborhood walkability was related to both measures of active transportation, but was not related to participation in sports teams and other indicators of leisure time physical activity. It is notable that these domain-specific associations still yielded walkability-related differences in overall MVPA assessed by accelerometers.

Two walkability by income effect modification trends were interpreted as significant (i.e., $p<.10$). For active travel to school, among adolescents in higher-income neighborhoods, the walkability effect was 1.6 walking/biking trips per week, but the walkability effect was only 0.6 trips per week in lower-income areas. The larger walkability effect on active transport to school in higher-income neighborhoods replicated a previous finding[39] and may indicate adolescents in lower-income areas have less choice about school travel modes due to less access to cars. Perhaps disparities in sidewalk presence and quality and safety of street crossings[18,19] lead parents to restrict active commuting to school among youth in lower-income neighborhoods even if the neighborhood is considered walkable.

The most important finding regarding sedentary behaviors was that the two sedentary behaviors most consistently linked to obesity, watching television/DVDs and riding in an automobile, were both related to walkability among adolescents. The effect sizes were modest but the cumulative effects over years could be substantial. The walkability effect for television and DVD viewing was a difference of about 13 min/day or 91 min/week. The walkability effect on time riding in a car was limited to adolescents in higher-income neighborhoods, and the difference was 8.5 min/day or 42 min/week. One interpretation is that safety concerns in lower-income neighborhoods lead parents to limit their adolescents' outdoor time and active travel, even within high-walkable areas, similar to an interpretation of a study of active travel to/from school.[40] Walkability was related to an index of 6 reported sedentary behaviors on school days but not during school ($p<.048$), but there was no walkability effect for objectively measured sedentary time. Total accelerometer-assessed sedentary time included several hours sitting at school, which would not be expected to be related to neighborhood walkability.

Although walkability was not directly related to weight status, adolescents who lived in lower-walkable, lower-income areas were most likely to be obese. Thus, low walkability may place lower-income youth at even higher risk for obesity than expected given the well-documented relations between socioeconomic status and obesity.[15]

Significant income main effects and effect modifications all indicated important income-based disparities in obesity, physical activity, and sedentary behaviors, consistent with prior findings documenting such disparities.[41] The income differences, along with effect modifications indicating additional disadvantages accruing to lower-income youth, provide a strong rationale for targeting lower-income neighborhoods for the most intensive youth physical activity promotion and obesity prevention efforts. Present results strengthen the rationale for built environment modifications to be part of interventions targeting lower-income neighborhoods.[1,3]

Strengths of the present study included a design that maximized variation in walkability and income, objective and reported measures of physical activity and sedentary time, examination of walkability by income effect modification, and a large sample size. Residential selection bias was minimized (a) because adolescents are not expected to make housing location decisions and (b) by adjusting for parent's use of activity-related characteristics in housing decisions. Weaknesses were the cross-sectional design and self-reported BMI, the latter of which could have led to more measurement error than objective data and type 2 error. The modest recruitment rate could result in a biased sample but may be largely due to the high respondent burden of completing extensive surveys and wearing devices for one week. However, recruitment rates did not differ significantly by study design quadrants.

Conclusion and Implications

Neighborhood walkability was significantly associated with more favorable objectively-measured total physical activity and frequency of active transportation. Present cross-sectional results justify more prospective and natural experiment studies to evaluate whether stronger evidence for a causal role of the built environment can be developed. Almost all walkability effects were found to apply across income categories, suggesting the potential of improving walkability to have population-wide effects. The present finding that neighborhood walkability was related to the two types of sedentary behaviors (TV/DVD viewing and riding in vehicles among higher-income adolescents) that have been linked with obesity may be the first such published results for youth. Because the study design was optimized to examine neighborhood walkability and income, present results add important evidence to the inconsistent findings regarding walkability and objective MVPA among youth.[9] Present results strongly support recommendations from numerous authoritative groups to enhance walkability of neighborhoods as a strategy for increasing physical activity of youth and the entire population.[1–6] A recent review indicated that the design of urban environments can contribute to a wide range of health problems in addition to physical activity.[42]

Several main effects and effect modifications involving income consistently found that youth in lower-income neighborhoods were less likely to obtain physical activity, sedentary behavior, and obesity benefits from living in walkable neighborhoods. Thus, present results strengthen the rationale for targeting health promotion interventions to lower-income neighborhoods.

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Terry Conway and Kelli Cain had full access to all of the data in the study and take responsibility for the integrity of the data and the accuracy of the data analysis. Carrie Geremia, BA made special contributions to data collection as paid staff. Kavita A Gavand at UCSD supported the preparation and submission of this manuscript as paid staff.

Abbreviations

TEAN	teen environment and neighborhood study

MVPA moderate-to-vigorous physical activity

BMI body mass index

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Highlights

- In walkable neighborhoods adolescents did more transport walking and total activity.
- In walkable neighborhoods adolescents had less TV time, time in cars, and total sitting.
- Walkability effects were similar for those in lower- and higher-income neighborhoods.

Table 1

Study Design Descriptives: Census Block Groups[a], Walkability, and Median Household Income by Study Design Quadrant defined by higher/lower walkability by higher/lower median income. The study was conducted in the Baltimore, Maryland-Washington, DC and Seattle-King County, Washington metropolitan areas 2009-2011.

Income	Region	Variable	Lower Walkability			Higher Walkability		
			Mean	Standard Deviation	Number of block groups	Mean	Standard Deviation	Number of block groups
Lower	Seattle-King County	Walkability Index[b]	−2.53	1.21	62	3.25	2.49	71
		Income[c]	$44,021	$7,075		$39,650	$8,713	
	Baltimore-Washington DC	Walkability Index[b]	−2.27	0.54	70	1.34	1.48	77
		Income[c]	$42,243	$5,196		$38,890	$8,402	
Higher	Seattle-King County	Walkability Index[b]	−3.15	1.28	36	2.82	1.28	59
		Income[c]	$78,185	$7,591		$70,807	$6,799	
	Baltimore-Washington DC	Walkability Index[b]	−3.32	1.04	37	1.21	1.05	35
		Income[c]	$77,776	$11,476		$71,416	$10,235	

[a] Using the set of block groups in each region that contained survey participants

[b] Walkability Index – regionally normalized (Z) value of the weighted sum of ZNetResidentialDensity_acre+2*ZIntersectionDensity_sqkm+ZRetailFloor Area+ZLandUseMix_fl_5 (20)

[c] Income – 2000 Census block group median household income

Table 2

Study measures. The study was conducted in the Baltimore, Maryland-Washington, DC and Seattle-King County, Washington metropolitan areas 2009–2011.

Variable	Reference	Description/sample items	Number of items; response options	Subscale score used in analyses	Psychometric properties (reference)
Physical Activity (PA)					
Total MVPA (Accelerometer)	Welk 2002 ([23])	Models: Actigraph 7164, 71256, GT1M, GT3X. Epoch: 30 seconds. Nonwear definition:30 min consecutive ‘0’ counts. Valid day: 10 hrs. Cut points: Freedson 3 METS; Evenson moderate. Requested wear time: 7 days (rewear requested if < 5 valid wearing days including 1 weekend). Data processing software: MeterPlus.	NA	Average minutes of MVPA per valid wearing day	Freedson et al., 1997 ([24]), Evenson et al., 2008 ([25]), Cain et al., 2013 ([26])
Active transport, non-school (Adolescent survey)	Developed by investigators	Typical frequency of walking or bicycling to/from 9 locations (e.g., recreation facility, friend’s house, park, food outlet) and skateboarding to various places.	10 items; 0=never, 1=≤ once/month, 2=once every other week, 3=once/week, 4=2-3 times/week, 5= 4+ times/week.	Mean of 10 items to represent average frequency of active transportation	NA
Active transport, to/from school (Adolescent survey)	Adapted from Centers for Disease Control Kids-Walk-to-School program (CDC, 2012)([27])	Number of days per week they traveled both to and from school by walking, bicycling or skateboarding.	10 items; To school (5 items) and from school (5 items): Scored 0-5 days.	Total number of active trips per week to and from school were summed (range = 0-10 trips).	Test-retest ICCs ranged from .51 to .84, and percent agreement from 73% to 95%. Timperio et al., 2006 ([28]); Joe et al., 2012 ([29])
PA in or near home (Adolescent survey)	Adapted from Sallis et al., 1993 ([30])	Typical frequency of being physically active in 7 common settings in or near home (e.g., home, nearby street, local park)	7 items; 0=never, 1=≤ once/month, 2=once every other week, 3=once/week, 4=2-3 times/week, 5= 4+ times/week.	Mean of 7 items to represent the average frequency of being physically active in our near home.	Test-retest ICC’s ranged from .31 to .65. Joe et al., 2012 ([29])

Variable	Reference	Description/sample items	Number of items; response options	Subscale score used in analyses	Psychometric properties (reference)
Total PA, outside of school (Adolescent survey)	Prochaska et al., 2000 ([31])	Number of days per week adolescent was physically active at least 60 minutes outside of PE or gym class (a) during the past 7 days and (b) during a typical week	2 items; Scored 0-7 days	Mean of 2 items to represent average days meeting PA guidelines (60+ min/day)	Excellent test-retest reliability and criterion validity. Prochaska 2000 ([31])
Sports and PA classes, outside of school (Adolescent survey)	Adapted from item developed by investigators	Number of sports teams or physical activity classes (excluding PE) adolescent participated in outside of school	1 item; 0=0, 1=1, 2=2, 3=3, 4=4 or more.	Number of teams/ classes used as continuous variable.	Test-retest of original item, ICC = .65. Joe et al., 2102 ([29])
Sedentary Time					
Total sedentary time (Accelerometer)	Welk 2002 ([23])	Models: Actigraph 7164, 71256, GT1M, GT3X. Epoch: 30 seconds. Non wear definition:30 min consecutive ‘0’ counts. Valid day: 10 hrs. Cut points: Freedson 3 METS; Evenson moderate. Requested wear time: 7 days (rewear requested if < 5 valid wearing days including 1 weekend). Data processing software: MeterPlus.	N/A	Average minutes of sedentary time per valid wearing day	Evenson 2008 ([25]), Cain 2013 ([26])
Time in sedentary behaviors (Adolescent survey)	Norman et al., 2005 ([32]), Rosenberg et al., 2010 ([33])	Time spent in sedentary activities on a typical school day during non-school hours. E.g., watching TV/DVDs/videos, playing sedentary video/computer games, riding in a motor vehicle	6 items; 0=None 1=15 min, 2=30 min 3=1 hr, 4=2 hrs, 5=3 hrs, 6=4+ hrs	Responses recoded to minutes and summed to create minutes per day engaged in sedentary behaviors	Good test-retest reliability (Norman et al, 2005 ([32])) and construct validity (Rosenberg et al., 2010 ([33]))

PA=physical activity, MVPA=moderate-to-vigorous physical activity

Table 3

Adolescents' physical activity, sedentary, and BMI measures with adjusted means by study design quadrants and tests for neighborhood income-by-walkability effect modification, or income and walkability main effects if income*walkability tests were non-significant (NS). The study was conducted in the Baltimore, Maryland-Washington, DC and Seattle-King County, Washington metropolitan areas 2009-2011.

Outcome	**Adjusted Means (SE)[a]**				**Tests of significance (p value)[b]**		
	Low walkable		**High walkable**		**Income × Walk effect modification (if p<.10)**	**Income main effect (if NS Income × Walk test)**	**Walkability main effect (if NS Income × Walk test)**
	Income		**Income**				
	Low	**High**	**Low**	**High**			
Physical Activity Measures:							
Accelerometer.							
Average MVPA min/day (3METS cutpoints)	53.2 (5.5)	56.5 (5.4)	57.8 (5.5)	61.1 (5.4)	—	**.057**	**.008**
Average MVPA min/day (Evenson cutpoints)	27.6 (4.2)	30.9 (4.1)	32.5 (4.2)	35.8 (4.1)	—	**.013**	**<.001**
Survey measures:							
Active transportation by walk, bike, skateboard to get places (mean 10 items)	0.79 (.10)	0.78 (.10)	1.02 (.10)	1.02 (.10)	—	.905	**<.001**
Active transport (walk, bike, skateboard) to or from school (trips per week)	1.53 (.32)	0.73 (.33)	2.01 (.33)	2.12 (.33)	**.067**	—	—
Number of sports teams or physical activity classes participated in outside of school	1.36 (.16)	1.61 (.16)	1.42 (.16)	1.67 (.16)	—	**.007**	.504
Days per week are physically active for 60+ min/day outside PE class	3.48 (.12)	3.70 (.13)	3.68 (.12)	3.91 (.13)	—	.104	.141
Scale indicating how often physically active in or near home (mean of 7 items)	1.99 (.07)	2.02 (.07)	1.92 (.07)	1.95 (.07)	—	.744	.385
Sedentary Measures:							
Accelerometer. Average sedentary min/day (<100 counts per min)	539.4 (13.2)	542.8 (12.9)	543.2 (13.2)	546.5 (12.8)	—	.439	.382
Survey: Sum of 6 types of sedentary activities: minutes per typical school day (non-school time)	404.2 (17.3)	373.5 (17.1)	378.6 (17.6)	347.8 (17.4)	—	**.017**	**.048**
Watching television/videos/DVDs (minutes per school day)	96.9 (6.1)	78.5 (6.1)	81.4 (6.3)	62.9 (6.3)	—	**<.001**	**.001**
Playing sedentary computer or video games (minutes per school day)	54.5 (7.0)	44.3 (7.1)	52.3 (7.1)	42.1 (7.2)	—	**.020**	.643

Outcome	Adjusted Means (SE)[a]				Tests of significance (p value)[b]		
	Low walkable		High walkable		Income × Walk effect modification (if p<.10)	Income main effect (if NS Income × Walk test)	Walkability main effect (if NS Income × Walk test)
	Income		Income				
	Low	High	Low	High			
Doing homework, including reading, writing or using the computer (min per school day)	89.4 (4.1)	101.3 (4.3)	89.0 (4.1)	101.0 (4.2)	—	**.012**	.936
Riding in a car/bus/etc. (min per school day)	52.2 (3.1)	53.3 (3.2)	54.0 (3.1)	44.8 (3.2)	**.092**	—	—
Using internet, emailing or other electronic media for leisure (minutes per school day)	77.9 (6.2)	72.4 (6.2)	76.9 (6.3)	71.4 (6.2)	—	.233	.832
Reading a book or magazine NOT for school, including comic books (minutes per school day)	53.7 (5.1)	51.8 (5.2)	52.2 (5.3)	50.3 (5.3)	—	.603	.682
Weight Status Measures:							
BMI percentile (age, sex-adjusted)	64.3 (2.5)	60.5 (2.6)	62.1 (2.6)	58.4 (2.7)	—	**.042**	.238
Percent Overweight or Obese (28.0% prevalence overall)	34.9 (3.2)	26.4 (3.1)	28.2 (3.1)	24.6 (3.1)	—	**.052**	.165
Percent Obese (≥95[th] percentile) (11.5% obese overall sample)	16.7 (2.6)	8.8 (2.0)	10.5 (2.1)	11.4 (2.3)	**.066**	—	—

[a]All models tested the following covariates and retained them if p <.15: *adolescent covariates* – age, gender, white/nonwhite race/ethnicity, has driver's license, attends school away from home, days per week lives at current address, works outside the home; *household covariates* – number of children in household, number of motor vehicles per licensed driver, years at current address, walkability-related reasons for moving here, and site (King County or Maryland regions). Accelerometer model and wearing time were included in analyses with accelerometer-based outcomes. Means are adjusted for covariates.

[b]Walkability-by-income interactions, if significant, are indicated; otherwise, the interaction was dropped from the model and the walkability and income main effects are presented.