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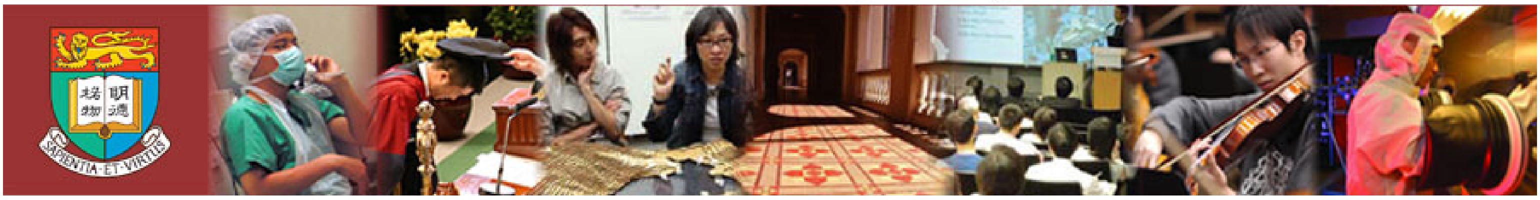

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Active Commuting to School and Association With Physical Activity and Adiposity Among US Youth

Jason A. Mendoza, Kathy Watson, Nga Nguyen, Ester Cerin, Tom Baranowski, and Theresa A. Nicklas

Background: Walking or bicycling to school (ie, active commuting) has shown promise for improving physical activity and preventing obesity in youth. Our objectives were to examine, among US youth, whether active commuting was inversely associated with adiposity and positively associated with moderate-to-vigorous physical activity (MVPA). We also examined whether MVPA mediated the relationships between active commuting and adiposity. ***Methods:*** Using data of participants aged 12 to 19 years from the US National Health and Nutrition Examination Survey 2003 to 2004 (n = 789 unweighted), we constructed multiple linear regression models that controlled for dietary energy intake and sociodemographics. The main exposure variable was active commuting. The outcomes were BMI z-score, waist circumference, skinfolds and objectively measured MVPA. The product-of-coefficients method was used to test for mediation. ***Results:*** Active commuting was inversely associated with BMI z-score ($\beta = -0.07$, $P = .046$) and skinfolds ($\beta = -0.06$, $P = .029$), and positively associated with overall daily ($\beta = 0.12$, $P = .024$) and before- and after-school ($\beta = 0.20$, $P < .001$) MVPA. Greater before- and after-school MVPA explained part of the relationship between active commuting and waist circumference (Sobel z = –1.98, $P = .048$). ***Conclusions:*** Active commuting was associated with greater MVPA and lower measures of adiposity among US youth. Before- and after-school MVPA mediated the relationships between active commuting and waist circumference.

Keywords: obesity, pediatric, walking, bicycling, school-based

The high prevalence of childhood and adolescent obesity is a major public health problem in the United States.[1–3] Recent reviews reported that higher levels of physical activity were associated with decreased risk of obesity.[4,5] However, only 7.6% of older adolescents from a nationally representative US sample met the recommended amount of moderate-to-vigorous physical activity (MVPA), compared with 42% of younger school-age children.[6] Furthermore, moderate-to-vigorous physical activity (MVPA) declined with age among US children and adolescents.[7] Factors related to MVPA need to be identified to help youth meet recommended physical activity goals.[8]

Increasing the proportion of trips made by children and adolescents walking or bicycling to school, hereinafter referred to as "active commuting," were objectives of Healthy People 2010 and identified as important to achieving the overall goal to "improve health, fitness, and quality of life through daily physical activity."[1] The 2008 Physical Activity Guidelines for Americans promoted walking to school as a practical strategy to promote youth physical activity.[9] In a recent review, students who regularly walked to school accumulated 20 more minutes of MVPA on weekdays than their peers who were driven in motor vehicles to school.[10] While previous studies reported positive associations between active commuting and physical activity,[11–16] some have reported no association.[17] Some studies identified differences in active commuting by age and gender.[10,12,18] The reported relationship between walking and bicycling to school and weight status was also mixed.[10] Some reported a positive association,[17] no association,[19,20] or an inverse association between active commuting and weight status.[14,18] The question of whether active commuting can improve daily physical activity and weight status is important since students may compensate for the physical activity of active commuting by decreasing other types of physical activity.[21,22] The mixed findings between active commuting and physical activity or weight status may be due to small sample sizes, subjectively measured physical activity, sampling from local or regional populations, or not controlling for dietary energy intake, which may confound relationships to energy balance. Finally, analyses should determine if

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the relationship between walking and bicycling to school and weight status was due to attaining greater amounts of physical activity. We address these gaps by examining (1) the association between active commuting and weight status/adiposity and (2) whether MVPA is responsible for the association between active commuting and weight status/adiposity (ie, mediated the relationship) among a nationally representative sample of US youth aged 12 to 19 years, while controlling for possible confounders such as sociodemographics and dietary energy intake. These questions are important because active commuting represents a potential population-level intervention to improve health for which physical activity and public health professionals may advocate. We hypothesized that (1) active commuting would be inversely associated with measures of adiposity, (2) active commuting would be positively related to MVPA, (3) MVPA would mediate the potential relationship between active commuting and adiposity, and (4) age group and gender would moderate the potential relationships among active commuting, MVPA, and adiposity.

Participants and Methods

Data Source

The National Health and Nutrition Examination Survey (NHANES) is a continuous cross-sectional survey that provides a nationally representative sample of the US noninstitutionalized civilian population through its stratified, multistage, probability cluster sampling design. The 2003–2004 NHANES was the first to include objectively measured physical activity data and 2 days of dietary recall data. Full details on NHANES methods have been reported elsewhere.[23] This secondary analysis on de-identified data were deemed exempt by the Institutional Review Board of Baylor College of Medicine.

Participants

Adolescents were included if they were aged 12 to 19 years and enrolled in school (12th grade or less; ie, did not have a high school diploma). Participants aged 17 to 19 years were further excluded if they were primarily employed and not in school full time. Subjects with missing data were excluded from analyses.

Outcome Variables

Height, weight, triceps skinfold thickness, and subscapular skinfold thickness were obtained using standardized techniques and equipment.[24] BMI was calculated as weight in kilograms divided by height in meters squared and their corresponding BMI z-scores were determined from the CDC growth charts.[25] Skinfolds were summed to provide an index of adiposity.

Physical activity was objectively measured by accelerometers (Model 7164, Actigraph, LLC; Ft. Walton Beach, FL) worn by participants over their right hip for 7 days while awake. Full details of the accelerometer protocol can be found elsewhere.[26] The Actigraph 7164, a unidirectional accelerometer that measured accelerations in the vertical plane, provided a measure of both the volume and intensity of movement over an extended period of time. It has provided a valid and reliable objective measure of physical activity in children.[27,28] Data were recorded in 1-minute epochs. To allow for comparison among studies using the NHANES 2003–2004 dataset, accelerometer data were excluded as per the criteria used by Troiano et al:[6] (1) monitors were not in calibration on return, (2) extended sequences of the maximum recordable value, and (3) sequences of 60 or more minutes in which activity never returned to 0. To estimate habitual physical activity, it is necessary to obtain accelerometer data on several days, termed "valid days." To be considered a valid day, the accelerometer must be worn for a minimum number of hours per day, termed "wear time." We used the definitions of a valid day and wear time, as defined previously by Troiano et al:[6] (1) a valid day was ≥ 10 hours of monitor wear; (2) nonwear time was defined by an interval of at least 60 consecutive minutes of no recordable activity, with allowance for 1 to 2 minutes of counts between 0 to 100; and (3) wear time was determined by subtracting nonwear time from 24 hours. We used participants' data that had at least 4 or more valid days of monitor wear. To determine MVPA,[6] a threshold of 4 metabolic equivalents was used; minutes that met or exceeded the criterion were summed to obtain a daily estimate of the number of MVPA minutes. We divided that sum by the number of valid days to obtain average daily MVPA. We also separately assessed the subset of before- and after-school time units for MVPA (Monday to Friday: 6:30–9 AM and 2:30–4 PM) since active commuting most likely occurred during those times. However, before- and after-school MVPA likely included other forms of physical activity besides active commuting, and therefore cannot be solely attributed to active commuting.

Main Exposure

Active commuting was assessed only among participants aged 12 years and older with the following questions ("SP" referred to "sample person"): (1) Over the past 30 days, [have/has] [you/SP] walked or bicycled as part of getting to and from work, or school, or to do errands? (2) [Over the past 30 days], how often did [you/SP] do this? and (3) On those days when [you/SP] walked or bicycled, about how long did [you/s/he] spend altogether doing this? From the questions above, we determined the minutes per day spent walking or bicycling to school, assuming that active commuting to work and for errands were infrequent as compared with school-related active commuting. Because these questions do not quantify active commuting in the same timeframe as the accelerometer data, we could not assign MVPA specifically to active commuting. Validity and reliability estimates for the main exposure questions were not available; however, previous studies examining student reported school travel demonstrated (1) acceptable test-retest reliability (kappa coefficient 0.96) and validity (kappa coefficient = 0.80) compared with parental report in a sample of children aged 8 to 11 years,[29] and (2) high test-retest reliability (97%) and validity (97.5%) compared with parental report in a sample of children aged 9 to 11 years.[17]

Covariates

We adjusted for several covariates (dietary energy intake, socioeconomic and demographic characteristics) that might confound the relationship between active commuting, physical activity, and weight status. Dietary energy intake was calculated from the mean of 2 24-hour recalls using the US Department of Agriculture's fully computerized Automated Multiple Pass Method.[30] The following socioeconomic and demographic covariates were included: 1) age in years as a continuous variable; 2) gender; 3) race/ethnicity categorized as non-Hispanic white, non-Hispanic black, Mexican-American, and Other; and 4) household income reported as the poverty-to-income ratio (PIR), which is the ratio of income to the family's appropriate poverty threshold as determined by the US Census Bureau.[31] PIR values less than 1 are below the poverty threshold, which is adjusted annually for inflation with the Consumer Price Index. PIR was provided by NHANES in the following 6 categories: <1, ≥ 1 <2, ≥ 2 <3, ≥ 3 <4, ≥ 4, <5, and ≥ 5 PIR.[23] For the moderator analyses, age was classified into 12 to 15 year olds and 16 to 19 years olds since older adolescents typically are eligible for a driver's license and might be more likely to commute by motor vehicle than their younger peers.

Analyses

Frequencies, percentages, means and standard deviations were used to describe participant characteristics. Exclusion due to missing data was done on an analysis-by-analysis basis. Chi-square tests of independence and analyses of variance were performed on participants included and excluded from analyses.

A series of regression analyses with active commuting as the independent variable and BMI z-score, waist circumference, or skinfolds as the dependent variable were performed to determine if active commuting was inversely associated with adiposity (hypothesis 1). A second series of regression analyses with active commuting as the independent variable and average daily MVPA or before- and after-school MVPA as the dependent variable were performed to determine if active commuting was positively related to MVPA (hypothesis 2).

A third set of regression analyses with both active commuting and MVPA as independent variables and BMI z-score, waist circumference, or skinfolds as the dependent variable were performed to determine, in part, if MVPA mediated (ie, explained) any potential relationship between active commuting and adiposity (hypothesis 3). More specifically, the product-of-coefficients method[32–34] was used to assess whether MVPA was a mediator using the Sobel formula.[33] Sociodemographics and dietary energy intake were included as covariates in all regression analyses. To assess whether age group or gender, separately, moderated the relationship among active commuting, MVPA, and adiposity, analyses were also stratified by age group and gender (hypothesis 4). A significance level of 0.05 was chosen for all analyses. Standardized regression coefficients and denoted std beta are presented; however, tests of mediation were performed using the nonstandardized regression coefficients. The total R^2 and partial R^2 are adjusted for the number of variables in the model. All analyses were performed using the survey weights and commands in SAS 9.1.3 (eg, PROC SURVEYREG) to take into account the complex survey design of NHANES.

Results

The initial sample of 827 (unweighted) participants met inclusionary criteria; however, 38 participants were excluded due to missing data. The final sample included in the analyses was 789 adolescents. Average age was 14.4 years and 48.6% were female. Table 1 lists frequencies, percentages and standard errors for gender and race/ethnicity. Table 1 also lists the means and standard errors for age, poverty-to-income ratio, dietary energy intake, anthropometrics, active commuting, and MVPA. Average time spent in active commuting for the entire sample was 8.5 minutes/day (including those who did not travel to school by active commuting in the past 30 days); if we excluded adolescents who did not use active commuting in the past 30 days, average time in active commuting was 18.4 minutes/day.

Comparing demographic characteristics of participants who were included (n = 789) versus excluded (n = 38) from analyses yielded a significant difference in age ($P = .016$). Excluded participants were older (15.3 ± 0.3 years) than included participants.

Controlling for age, gender, race/ethnicity, poverty-to-income ratio, and energy intake (Table 2), active commuting was inversely associated with BMI z-score (std. beta = –0.07, $P = .046$, partial $R^2 = .004$; total model $R^2 = .05$) and skinfolds (std. beta = –0.06, $P = .029$, partial $R^2 = .004$; total model $R^2 = .12$). Active commuting was inversely associated with waist circumference, although this association did not reach statistical significance (std. beta –0.06, $P = .093$, partial $R^2 = .003$; total model $R^2 = .08$). Active commuting was positively associated with average daily MVPA (std. beta = 0.12, $P = .024$, partial $R^2 = .02$; total model $R^2 = .31$) and before- and after-school MVPA (std. beta = 0.20, $P < .001$, partial $R^2 = .06$; total model $R^2 = .20$). No significant interactions were found by age group or gender effects on any adiposity outcomes (results not presented).

For the mediation analysis (Tables 3 and 4), before- and after-school MVPA significantly mediated the relationship between active commuting and waist

Table 1 Demographic Characteristics

Characteristics	n	% (SE)
Gender		
Female	379	48.6 (1.7)
Race/ethnicity		
Non-Hispanic White	198	64.7 (5.2)
Non-Hispanic Black	276	15.2 (2.3)
Hispanic	276	12.3 (3.1)
Other	39	7.8 (2.0)
Characteristics	**n**	**M (SE)**
Age (years)	789	14.4 (0.1)
Poverty-to-income ratio	789	2.7 (0.1)
Average energy intake (kcals)	789	2,211 (42)
BMI z-score	789	0.61 (0.1)
Waist circumference (cm)	789	79.9 (0.7)
Skinfolds (triceps + subscapular; mm)	789	29.7 (0.9)
ACS (min/day)	789	8.5 (1.6)
Average daily MVPA (min/day)	789	30.0 (2.0)
Weekday average MVPA min before/after school	789	9.0 (0.9)

Abbreviations: SE, Standard Error; M, Mean; MVPA, moderate-to-vigorous physical activity; ACS, Active Commuting to School.

circumference (Sobel z = –1.98, P = .048). Before- and after-school MVPA had nonsignificant but borderline mediation of active commuting and BMI z-score (Sobel z = –1.68, P = .093) and skinfolds (Sobel z = –1.81, P = .070). Average daily minutes of MVPA mediated no relationships ($P > .1$).

Stratification analyses did not yield any significant mediated relationships, thus, indicating that gender and age group did not differently influence or moderate any potential mediation of MVPA to the relationship between active commuting and adiposity.

Because active commuting might also be related to light physical activity (the lower cutpoint defined as ≥ 101 counts per minute[35]), we conducted parallel analyses to include the sum of light-, moderate-, and vigorous-physical activity (LMVPA). No significant association was found between active commuting to school (ACS) and LMVPA (P = .603 for total daily LMVPA or P = .169 for before- and after-school LMVPA), controlling for covariates. Similarly, LMVPA did not mediate the relationship between ACS and BMI z-score, waist circumference, or skinfolds (all $P > .05$).

Discussion

To our knowledge, we are the first to report the association between active commuting and objectively measured physical activity and adiposity at the population-level for US youth. Greater minutes of active commuting were associated with lower BMI z-score and skinfolds (hypothesis 1). The effect sizes were modest and smaller compared with other studies that reported inverse associations.[10–16] Unlike other active commuting studies, since obesity is the result of energy imbalance,[36] we controlled for confounding by dietary energy intake, which should better estimate the impact of active commuting on adiposity. The multivariable models indicated that active commuting accounted for less than 1% of the variability in BMI z-score and skinfolds, respectively, which was consistent with other studies on risk factors for childhood obesity and adiposity.[37] Clearly, long-term studies on active commuting that control for energy intake and use objective methods for assessment of physical activity are necessary to better characterize this relationship.

US youth who actively commuted to school achieved greater minutes of MVPA (hypothesis 2). These results were consistent with previous smaller studies.[10–16,38] Our data suggest that if US youth spent a total of 30 minutes per day actively commuting to and from school (15 minutes each way), they would obtain, on average, 4.5 additional minutes of MVPA per day or 7.5% of the recommended amount. Since most US youth attend school and only approximately 7 to 8% of US youth aged 12 to 19 years met the recommended 60 minutes of MVPA per day in 2003 to 2004,[6] active commuting may represent an opportunity to broadly improve children's and adolescents' MVPA, and ultimately overall health. Policy-makers, urban planners, and school officials should consider these health benefits with regard to school siting decisions and implementation of walk to school programs. Preliminary experimental evidence from school-based trials on the impact of Walking School Buses to improve children's active commuting appears

Table 2 Standardized Coefficients (Std Beta) for Active Commuting to School's (ACS) Relationship to Adiposity (Regressions Series 1) or Moderate-to-Vigorous Physical Activity (MVPA; Regression Series 2)

	BMI z-score		Waist circumference (cm)		Skinfolds (mm)	
Regression: series 1	**Std Beta**	***P***	**Std Beta**	***P***	**Std Beta**	***P***
ACS	–0.07	0.046	–0.06	0.093	–0.06	0.029
Age	–0.03	0.504	0.21	0.000	0.06	0.130
Gender (ref: female)						
Male	0.09	0.087	0.12	0.038	–0.18	0.005
Race/ethnicity (ref: Non-Hispanic White)						
Non-Hispanic Black	0.00	0.917	–0.13	0.008	–0.14	0.009
Hispanic	–0.08	0.104	–0.07	0.166	–0.08	0.097
Other	–0.11	0.058	–0.12	0.004	–0.08	0.039
Poverty-to-income ratio	–0.12	0.066	–0.13	0.033	–0.10	0.087
Energy (kcals)	–0.16	0.001	–0.16	0.001	–0.20	0.001
R^2 (partial R^2 for ACS)	0.05 (0.004)		0.08 (0.003)		0.12 (0.004)	

	MVPA min/day		MVPA min before/after school	
Regression: series 2	**Std Beta**	***P***	**Std Beta**	***P***
ACS	0.12	0.024	0.20	0.000
Age	–0.32	0.000	–0.16	0.002
Gender (ref: female)				
Male	0.29	0.000	0.15	0.001
Race/ethnicity (ref: Non-Hispanic White)				
Non-Hispanic Black	0.12	0.032	0.12	0.043
Hispanic	0.11	0.058	0.16	0.016
Other	0.07	0.040	0.15	0.003
Poverty-to-income ratio	–0.01	0.827	–0.01	0.866
Energy intake (kcals)	0.04	0.375	0.05	0.147
R^2 (partial R^2 for ACS)	0.31 (0.02)		0.20 (0.06)	

Abbreviations: Std, Standardized; MVPA, Moderate-to-vigorous physical activity; ACS, Active Commuting to School; min, Minutes.

Table 3 Standardized Coefficients* (Std Beta) for Active Commuting to School's (ACS) Relationship to Adiposity, Controlling for Moderate-to-Vigorous Physical Activity.

	BMI z-score		Waist circumference		Skinfolds	
	Std Beta	***P***	**Std Beta**	***P***	**Std Beta**	***P***
Mediator: MVPA min/day						
ACS	–0.07	0.077	–0.05	0.143	–0.06	0.033
MVPA min/day	–0.07	0.260	–0.09	0.155	–0.03	0.560
R^2 (partial R^2 for ACS)	0.05 (0.003)		0.09 (0.001)		0.12 (0.003)	
Mediator: MVPA min before/after school						
ACS	–0.06	0.112	–0.04	0.257	–0.05	0.079
MVPA min before/after school	–0.08	0.123	–0.11	0.062	–0.09	0.080
R^2 (partial R^2 for ACS)	0.05 (0.002)		0.09 (<0.001)		0.13 (0.001)	

Abbreviations: Std, Standardized; MVPA, Moderate-to-vigorous physical activity; ACS, Active Commuting to School.

* Additionally controlled for age, gender, race/ethnicity, poverty-to-income ratio, and dietary energy intake.

Table 4 Tests of Mediation Effects

	Sobel	
	z	P
Outcome: BMI z-score		
Mediator		
MVPA min/day	−0.93	0.353
MVPA min before/after school	−1.68	0.093
Outcome: waist circumference		
Mediator		
MVPA min/day	−1.30	0.194
MVPA min before/after school	−1.98	0.048
Outcome: skinfolds		
Mediator		
MVPA min/day	−0.56	0.574
MVPA min before/after school	−1.81	0.070

Abbreviations: MVPA, Moderate-to-vigorous physical activity.

promising for both middle/high-income students,[38–40] and low-income students.[41] These types of programs make active commuting to school feasible for students who live a long distance from school, by providing a designated, safe drop-off point closer to school from which they may then actively commute. This in turn may decrease traffic volumes/congestion, pedestrian injury risk, and vehicle pollution around schools and deserves further study.

Mediation analyses demonstrated that the relationship between active commuting and central adiposity was significantly explained by before- and after-school MVPA (hypothesis 3). Similar analyses found nonsignificant, borderline mediation by before- and after-school MVPA for the relationships between active commuting and BMI z-score or skinfolds. Further study is necessary to these confirm relationships. Average daily MVPA may not have mediated the relationships, perhaps because active commuting occurred most frequently before and after school, and thereby was compensated by other types of activity during the rest of the day.

Stratification of the analyses revealed no differential mediation of MVPA for the relationship between active commuting and adiposity by age group or gender (hypothesis 4). While some studies have found differences in active commuting by age and gender, results across studies are mixed.[10] Comparison with previous studies was difficult, since this study was the first to examine differences by age and gender for MVPA mediating the relationship between active commuting and adiposity. Clearly, further studies are necessary to verify this finding.Strengths of this study include its large nationally representative sample, use of a validated objective measure for physical activity, anthropometric outcomes were measured per protocol (and not self reported), and controlling for dietary energy intake. Like all studies, there are several important limitations: (1) This study was cross-sectional and thus causality cannot be determined; (2) NHANES was not specifically designed for our research questions and no data were available on distance from school, the built environment, or neighborhood safety, which have been important correlates of active commuting;[10] (3) The main exposure of active commuting was assessed by participant self-report and validity is not known, however, similar youth self-reports of active commuting had acceptable reliability and validity;[17,29] (4) The accelerometers measured physical activity over 4 to 7 days, while the active commuting questions applied to a much larger interval (the past 30 days). Assuming errors were random, this mismatch may have biased estimates toward the null hypothesis and may explain why minutes of active commuting were not equivalent to minutes of MVPA; (5) Participants may have over-reported minutes of active commuting, some of the active commuting time was of light intensity, or participants who actively commute may have spent less time in other forms of MVPA; (6) The time intervals for before-and after-school were estimated and not likely identical to actual times walking to and from school, which will vary per student; (7) Some participants were excluded from analyses due to missing data—these participants tended to be slightly older, which may limit external validity.

Conclusions

Active commuting to school was independently associated with greater levels of physical activity and lower levels of body fatness and obesity, while controlling for confounding by dietary energy intake, among a nationally representative sample of US youth. Before-and after-school MVPA mediated the relationship between active commuting and central adiposity. Active commuting could have significant population-level impact for physical activity promotion and obesity prevention for US youth. Further research, especially well-designed longitudinal studies, is necessary to better quantitate these relationships.

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