Published in final edited form as:
Am J Prev Med. 2013 March ; 44(3): 231–238. doi:10.1016/j.amepre.2012.10.024.

Neighborhood Design for Walking and Biking:

Physical Activity and Body Mass Index

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Abstract

Background—Neighborhood designs often relate to physical activity and to BMI.

Purpose—Does neighborhood walkability/bikeability relate to BMI and obesity risk and does moderate-to-vigorous physical activity (MVPA) account for some of the relationship?

Methods—Census 2000 provided walkability/bikeability measures—block group proportions of workers who walk or bike to work, housing age, and population density—and National Health and Nutrition Examination Study (NHANES 2003–2006) provided MVPA accelerometer measures. Regression analyses (2011–2012) adjusted for geographic clustering and multiple control variables.

Results—Greater density and older housing were associated with lower male BMI in bivariate analyses, but there were no density and housing age effects in multivariate models. For women, greater proportions of neighborhood workers who walk to work (M=0.02) and more MVPA was associated with lower BMI and lower obesity risk. For men, greater proportions of workers who bike to work (M=0.004) and more MVPA was associated with lower BMI and obesity risk. For both effects, MVPA partially mediated the relationships between walkability/bikeability and BMI. If such associations are causal, doubling walk and bike-to-work proportions (to 0.04 and 0.008) would have –0.3 and –0.33 effects on the average BMIs of adult women and men living in the neighborhood. This equates to 1.5 lbs for a 64" woman and 2.3 lbs for a 69" man.

Conclusions—Although walking/biking to work is rare in the U.S., greater proportions of such workers in neighborhoods relate to lower weight and higher MVPA. Bikeability merits greater attention as a modifiable activity-friendliness factor, particularly for men.

Introduction

A growing body of work relates activity-friendly neighborhood environmental designs to measured physical activity, or separately, to healthier adult BMIs.[1,2] The underlying conceptualization is that environmental supports for walking or biking will enable residents

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No other financial disclosures were reported by the authors of this paper.

to be more active and thereby sustain healthy BMIs. Yet few neighborhood studies actually include both physical activity and BMI in the same model. The present research relates activity-friendly neighborhood environmental indicators, including novel evidence of bikeability, to objective measures of physical activity and BMI.

Many studies have assessed how “walkability”—neighborhood design features that support walking—relates to walking. These measures typically include aspects of the “3Ds” of walkability: population **d**ensity, land-use **d**iversity, and pedestrian-friendly street **d**esign.[3] The present study employs four census indicators of activity-friendly environments that are available for all U.S. communities, have received substantial empirical support,[4,5] and could guide community interventions. These include older neighborhoods, greater density, and greater proportions of workers who walk or bike to work.

Older neighborhoods have many modifiable 3D design features[6] that might encourage active transportation[7] and healthier weight[8,9]: high population densities; diverse destinations; and pleasant, tree-shaded sidewalks.[6,10] Higher population density creates the critical mass needed to provide neighborhood destinations such as transit stops and restaurants and has been related to more physical activity[11,12] and lower BMI.[8,13–18] Land-use diversity, such as homes near workplaces,[8,9] brings desired destinations within walking distance. Diversity is defined in various ways[19] and is often related to healthier weight.[8,17–22]

Few studies of neighborhood design and weight include “bikeability” (i.e., cyclist-friendly design), although bikeable environments may support physical activities for many, not just for cyclists. Biking is more likely in environments that offer density,[12,23] diversity,[23] activity-friendly design features (e.g., lower speeds on roads[23]); or a combination of the 3Ds.[24] These studies generally, but not universally,[25] suggest that bikeability is similar to walkability. Bikeable environments may also include additional features, such as bike signage and traffic lights,[23] bike lanes,[26] or road-separated bike paths,[27] bike lane connectivity,[28] and nearby sports and park spaces[29,30] or natural amenities.[12] Further, bicycling involves longer trips than walking. Thus, bikeable and walkable environments may be sufficiently distinct to have unique relationships with residents’ physical activity and BMI.

Walkability/bikeability often relates to physical activity and/or BMI, but not to both outcomes in the same model. For example, in Baltimore and Seattle, 3D walkability related to more adult MVPA and, separately, to less overweight/obesity risk.[31] In Atlanta, the 3Ds related to more walking and, separately, to less risk of overweight and obesity, for white men only.[32] For National Health and Nutrition Examination Study (NHANES) 1988–1994 data, county walkability related to self-reported walking and, separately, to measured weight.[33]

One study in Ghent, Belgium tested whether activity mediated the relationship between walkability and self-reported BMI in low- and high-walkability neighborhoods.[34] Surprisingly, walkability was not related to BMI but higher accelerometer-measured MVPA was related to lower BMI. The authors argued that MVPA mediated the relationship between walkability and weight. The present study tests for mediation in the U.S., where walkability/bikeability and active transportation are lower.[35,36] Specifically, the current paper examines (1) whether walkability/bikeability relates to BMI and obesity risk; and (2) whether this relationship diminishes when MVPA is included in the analysis, suggesting a causal role for MVPA.

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Methods

Data from NHANES 2003–2004 and 2005–2006[37] included 20,470 individuals from 60 different geographic areas,[38] with cold areas visited during warm months.[39] Participants were interviewed, measured for BMI, and those who could walk were invited to wear accelerometers (Actigraph Model 7164) for 7 days.[40] The Research Data Center (National Center for Health Statistics, CDC) merged 2000 Census walkability/bikeability data to NHANES data.

Exclusions

Accelerometer data were discarded if accelerometers were poorly calibrated or yielded improbable values.[39] For this study, younger adults (aged <25 years) were excluded because of their residential instability,[41] and older adults (aged ≥65 years) were excluded because of their more complicated relationships between BMI and health.[42] From an initial pool of 6328 age-eligible adults, additional sequential exclusions included: incomplete BMI data (n=360); underweight (n=77); BMI>60 (n=9); pregnancy[43] (n=374); <4 days of valid (i.e., ≥10 hours/day) accelerometer wear (n=1769); missing data on education (n=1); census variables (n=208); and marital status (n=2). Participants with and without ≥4 days of accelerometer wear had similar BMIs. The final sample size was 3528.

Variable Definitions

Control variables—Individual-level NHANES control variables included: age, marital status (married=1, else=0); education (<high school, high school graduate (reference category); some college, college graduate); race/ethnicity (non-Hispanic white (reference), non-Hispanic black, Hispanic); smoker (currently smokes cigarettes=1; else= 0); average caloric intake from two 24-hour recalls, and hours of accelerometer wear.[34]

Economic status—This variable was assessed with proportions of individuals in three categories of household income-to-poverty-level ratios: <100%, 100%–200%, and >200% (reference) of the poverty level. Missing economic data were imputed by substituting the mean plus a random number (M=0 and SD=SD of the distribution for nonmissing values). Single-day caloric intake was used for individuals missing 1 day of food intake, and imputation (as above) was used for those missing both days. Controls also included median family income, median age of residents in the block group, and proportions that were Hispanic and non-Hispanic black, Hawaiian–Pacific Islander, and Asian.[44,45]

Walkability/bikeability measures—Census block group walkability/bikeability measures included neighborhood housing age (median years); population density (in 1000s per square mile); and proportions of employed residents who walk or bike to work. Note that <3% of individuals in the U.S. walk or bike to work. Thus, any relationship between walkability/bikeability and BMI is unlikely to be due to resident commuters who walk or bike. Instead, walkability/bikeability indicators are proxies for a range of walkability/bikeability conditions that may affect the broader resident population. BMI was calculated by standard formula[2] from clinical examination measures. Obesity was dichotomous (1 for 30<BMI<60 obese, and 0 for 18.5<BMI<25 healthy weight).

Accelerometer-based physical activity measures—Procedures to derive MVPA measures described in Troiano et al.'s[39] analysis of NHANES 2003–2004 data were applied to NHANES 2003–2006,[39] including measures of valid wear (≥4 days of ≥10 hours of accelerometer wear), nonwear (≥60 minutes of zero counts), and MVPA threshold (2020 accelerometer counts/minute[39,46]).

Validation measures—Census measures of percentage of workers aged ≥16 years who walk/bike to work were validated against more-traditional measures of walkability for 66,348 U.S. census tracts.[47] Traditional walkability measures included tract-level intersection densities (3-, 4-, and 5-way intersections of streets posted as ≤25 mph), population density, and median housing age.

Data Analysis

Analyses included regression tests of BMI and logistic regression tests of obese versus healthy weight (SAS 9.2 proc surveyreg and proc surveylogistic), correcting for geographic clustering and using NHANES sample weights. Analyses (not presented) revealed no walkability effects in multivariate tests of healthy weight versus overweight individuals. Mediation tests used the Freedman and Schatzkin test of differences in coefficients produced when MVPA was added to the model[48] (see MacKinnon et al.[49] for details).

Gender-specific models were estimated, consistent with past research.[8,32] For the logistic equations, pseudo-R^2 values were calculated according to the Cragg–Uhler[2] equation. No problematic levels of multicollinearity were detected. Correlations among the four walkability/bikeability measures averaged r =0.28 for women and 0.30 for men, ranging from 0.18 (housing age with bike to work for women and men) to 0.36 for women (for density with housing age) and 0.41 for men (for density with walk to work).

Results

Validation Tests

The validation study (full results available from authors on request), based on census tract measures, demonstrated that walkability/bikeability measures were related to traditional walkability measures. Walk to work was a function of street intersection connectivity (b= 0.045, SE=0.003), population density (b=0.097, SE=0.002), and building age (b=0.072, SE=0.002), with an R^2 of 0.11. Bike to work was a function of street connectivity (b=0.020, SE=0.001), population density (b=0.003, SE=0.000), and building age (b=0.004, SE=0.000) with an R^2 of 0.032. Effects remained significant, albeit smaller, when tract-level median household income, race/ethnicity composition, median age, and percentage of college graduates were added as controls. Results provide sufficient validation to proceed with walk/bike to work as measures of walkability/bikeability.

Main Study

Descriptive results (Appendixes A and B, available online at www.ajpmonline.org) show that the average adult is overweight and that men are more active than women. Among the four variables that index activity-friendly environments—greater density, older housing, and greater proportions who walk or bike to work—bivariate relationships in the expected directions were generally observed for men. For men, greater density and greater proportions who walk or bike to work were related to greater MVPA. For men, these variables plus greater housing age were related to lower BMI. For women, greater densities and greater proportions walking and biking to work were related to more MVPA, but only the higher proportions of employed residents walking to work were related to lower female BMI.

Baseline multivariate results, without MVPA (Table 1) reveal predictable associations between sociodemographic and neighborhood variables and weight outcomes. In most models, younger ages, college degrees, and smoking were related to lower BMI and obesity risk and black race was associated with higher BMI and obesity risk. Less accelerometer wear and lower median household income were related to higher weights in three of four models. Racial and ethnic composition predictors were generally insignificant (except that more Asians in the neighborhood was related to lower male BMI). Food intake measures were not related to greater weight except in the female BMI model. For men, even simple correlations between food intake and weight were nonsignificant.

Two walkability/bikeability indicators were consistently associated with lower weight outcomes. For women, the proportion of neighbors who walk to work was related to lower BMI and lower obesity risk. For men, the proportion of neighbors who bike to work was related to lower BMI and lower obesity risk. In the multivariate equations, neither population density nor housing age was related to weight, despite the bivariate associations among men, summarized above.

The MVPA variable was added to the final models (Tables 1 and 2) to examine whether MVPA was related to BMI and whether that relationship attenuated the relationships between walkability/bikeability and BMI. In all cases, more MVPA minutes/day was related to lower BMIs and risks of obesity. The change in R^2 was significant (ΔR^2 female BMI $F(1,1695)=28.28$, $p<0.001$; male BMI $F(1, 1783)=74.79$, $p<0.001$). Mediation tests showed that adding MVPA reduced the significant relationship between proportion walking to work and female BMI, $t(1718)= -12.58$.[48] Similarly, adding MVPA reduced the significant relationship between proportions biking to work and male BMI: $t(1806)= -3.74$. These tests indicate that MVPA partially explains the gender-specific walkability/bikeability relationships to BMI. Both neighborhood walkability/bikeability and MVPA also have independent and significant relationships with BMI and obesity risk.

Discussion

Walkability and bikeability features were predictors of lower BMI and higher obesity risk (Tables 1 and 2). Recall that these findings are unlikely to be driven by healthier weights of those who walk or bike to work, given that they account for <3% of employed individuals in the neighborhood. In past research, the walk-to-work variable has been understood as an indicator of mixed land use, given that homes and employment sites are present within a walkable distance.[8] Bikeability may index a broader underlying concept of activity-friendliness, given that bikeability reflects both the 3Ds of walkability and other features, such as bike paths and calmed automobile traffic.[29,50] The present study is the first to examine the relationship of neighborhood characteristics to physical activity and BMI using a nationally representative U.S. sample with objective BMI and physical activity variables and multiple control variables. The walkability measure and the new bikeability measure suggest additional ways in which physical environments may support more activity and healthier body weight.

The direct effects of the proportion of workers in the neighborhood who walk to work for female MVPA and BMI and proportions of workers in the neighborhood who bike to work for male MVPA and BMI were roughly equivalent to the effects of Hispanic ethnicity, smoking, and low education levels, according to simple correlations (Appendix A, available online at www.ajpmonline.org). The multivariate associations for these walkability/bikeability variables are about as strong as for standard sociodemographic predictors.

In the case of women, the estimated effect of doubling from 0.02 to 0.04 the average proportion of workers in the neighborhood who walk to work on a woman's BMI is –0.3 (or approximately a 1.5-pound reduction for a woman who is 64 inches tall). This effect size is equivalent to increasing the median household income of the census block group by $10,000 per year, holding other factors constant. Similarly, doubling the bike-to-work proportion from 0.004 to 0.008 (the average proportion in the 90 largest U.S. cities[51]) would have an effect on men's BMI of –0.33 (about 2.31 pounds for a 69 inch tall male). Thus, if these correlational findings are truly causal, improving walkability/bikeability features of a neighborhood may prove to be modifiable public health policy levers that could affect residents' weight.

This study also confirmed patterns found in past studies that have shown that MVPA is related to BMI in NHANES.[52–54] MVPA reduced the relationship between walkability/bikeability and BMI, which was similar to the findings of Van Dyck et al. in Ghent.[34] The current study, unlike Van Dyck et al., found direct relationships between walkability/bikeability and weight. The current study also utilized objective weight measures and more control variables than the Ghent study, including controls for caloric intake, which enhances confidence in the walkability/bikeability effects.

Walkability and bikeability had gender-specific relationships with BMI and obesity risk. Given that men are more likely to bike than women, bikeable neighborhoods may provide them with more-feasible models of MVPA; such speculation requires new research. Together, these results suggest that it may be important to test gender-specific models and to distinguish between walking and biking when asking about neighborhood supports for active transportation, although the two modes are often combined into single questions in current health surveys.[55] Future research is also needed to provide better measures of bikeable environments and dissemination of results to further research-based environmental supports for healthy and safe biking. Both greater density and older age of housing were related to lower BMI for men in simple correlations, but there were no effects of these variables in the multivariate models. Thus, these measures may still serve as useful walkability indicators, depending on the mix of variables in multivariate models.

Limitations

Results are tempered by several limitations. The cross-sectional data precluded drawing causal conclusions. Census data provide a few indicators of mixed use and walkability/bikeability, and NHANES data sampled only 60 U.S. geographic areas. Many participants were dropped for <4 days of accelerometer wear, although BMI measures were similar for both groups. The R^2 values were low, but small effects across large populations can mean substantial health benefits,[56] and are consistent with effects found in other studies of walkability and weight measures.[20,57] As noted above, the walkability/bikeability direct effects were similar in magnitude to other more established health indicators, such as Hispanic ethnicity, smoking, and low education levels. Finally, the data did not allow exploration of a wide range of other variables that might attract lower BMI individuals to walkable and bikeable neighborhoods, such as attitudes, natural amenities, or job/educational opportunities.[12,58,59]

Conclusion

The relatively novel results for bikeability merit additional research and policy attention. Research has shown that providing better environments for biking can lead to an increase in biking.[60] However, the current study suggests that bikeable neighborhoods also support greater neighborhood-wide healthy weights among men, not just among the few cyclist commuters. This may be due to the particular activity-friendly design qualities of bike paths or biking destinations, the attraction of activity-inclined residents, or salient modeling of activity by cyclists. The next step in research is to investigate whether these or other mechanisms underlie the connections between bikeable environments, MVPA, and healthy weight.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

Acknowledgments

This research was supported by NIH NIDDK Grant Number 1R21DK080406 and NIDDK ARRA 3R21 DK080406. The funding agency had no involvement in study design, data analysis, interpretation of the results, or decision to submit this article for publication. The findings and conclusions in this paper are those of the authors and do not necessarily represent the views of the Research Data Center (RDC), National Center for Health Statistics, CDC. The authors thank Nataliya Kravets, Vijay Gambhir, and Santosh Gambhir from the RDC for their technical assistance.

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Table 1

BMI: walkability/bikeability baseline model and physical activity model

	Women				Men			
	Walk/bikeability		Physical activity		Walk/bikeability		Physical activity	
Variables (proportions, unless noted)	**B**	**SE**	**B**	**SE**	**B**	**SE**	**B**	**SE**
Intercept	**31.23**	**2.14** **	**31.63**	**2.20** **	**30.23**	**1.40** **	**31.97**	**1.47** **
Control variables								
Age (years)	**0.07**	**0.02** **	**0.05**	**0.02** **	**0.04**	**0.02** *	0.02	0.02
Married	−0.96	0.62	−0.90	0.61	0.35	0.37	0.4	0.35
< high school	−0.83	0.60	−0.41	0.58	−0.93	0.59	−0.85	0.58
Some college	0.02	0.56	0.10	0.54	−0.6	0.50	−0.65	0.49
College grad	**−1.97**	**0.54** **	**−1.77**	**0.54** **	**−1.32**	**0.46** **	**−1.36**	**0.45** **
Black	**1.53**	**0.57** **	**1.47**	**0.56** **	**1.49**	**0.57** **	**1.53**	**0.54** **
Hispanic	−0.62	0.65	−0.60	0.66	0.71	0.56	1.09	0.58
Other race	**−3.41**	**0.62** **	**−3.51**	**0.62** **	−0.64	0.62	−1.05	0.57
<poverty	0.79	0.64	0.99	0.66	**−1.43**	**0.47** **	**−1.56**	**0.44** **
< 1-2x poverty	−0.28	0.50	−0.23	0.50	−0.82	0.34 *	−0.67	0.37
Calories (100s)	**0.08**	**0.04** *	**0.08**	**0.04** *	−0.01	0.02	−0.01	0.02
Smoker	**−1.82**	**0.53** **	**−1.81**	**0.51** **	**−1.54**	**0.28** **	**−1.65**	**0.29** **
Device worn (hours/wk)	**−0.03**	**0.01** **	**−0.02**	**0.01** **	**−0.03**	**0.01** **	**−0.02**	**0.01** **
Income ($1000s) BG	**−0.03**	**0.01** **	**−0.03**	**0.01** **	**−0.02**	**0.01** *	−0.01	0.01
Age (years) BG	−0.02	0.05	−0.03	0.05	0.05	0.03	0.04	0.03
Black-BG	0.88	1.01	0.75	0.98	−1.71	0.93	−1.84	0.93
Hawaiian-Pacific Islander-BG	12.14	24.8	12.73	26.2	−30.4	17.1	**−34.66**	**16.30** *
Asian-BG	−1.20	2.62	−1.67	2.56	**−5.58**	**1.97** **	**−5.80**	**1.88** **
Hispanic-BG	−0.17	0.94	−0.45	0.92	−0.56	0.95	−0.87	0.95
Walkability/bikeability variables								
Density (1000s /sq.mile)-BG	0.02	0.02	0.03	0.02	−0.02	0.02	−0.02	0.02
Housing age (years)-BG	0.00	0.01	0.00	0.01	0.00	0.01	0.00	0.01
Walk to work-BG	**−16.40**	**4.63** **	**−15.19**	**4.72** **	0.24	3.35	0.89	3.56
Bike to work-BG	−12.9	19.60	−8.31	18.38	**−24.74**	**8.60** **	**−21.22**	**8.31** *
Physical activity								
MVPA (minutes./day)			**−0.04**	**0.01** **			**−0.04**	**0.01** **
R2	0.10		0.12		0.08		0.12	

Note: Boldface indicates significance.

BG, block group

** $p<0.01$,

* $p<0.05$

Table 2

Obese versus healthy weight: logistic regressions

	Women				Men			
	Walk/bikeability		Physical activity		Walk/bikeability		Physical activity	
	OR	(95% CI)	OR	(95% CI)	OR	(95% CI)	OR	(95% CI)
Control variables								
Age	1.02	(1.01, 1.04)**	1.02	(1.00, 1.03)**	1.04	1.02, 1.06)**	1.02	(1.00, 1.04)*
Married	0.83	(0.59, 1.17)	0.83	(0.58, 1.18)	1.13	0.73, 1.76)	1.18	(0.76, 1.82)
< high school	0.86	(0.54, 1.40)	0.96	(0.59, 1.56)	0.57	0.31, 1.05)	0.57	(0.31, 1.06)
Some college	0.86	(0.55, 1.33)	0.92	(0.60, 1.42)	0.74	(0.46, 1.20)	0.71	(0.42, 1.20)
College grad	0.44	(0.33, 0.60)**	0.51	(0.38, 0.70)**	0.39	(0.23, 0.65)**	0.36	(0.21, 0.60)**
Black	2.40	(1.58, 3.64)**	2.40	(1.58, 3.64)**	2.09	(1.10, 3.98)*	2.20	(1.11, 4.34)*
Hispanic	0.94	(0.56, 1.60)	0.97	(0.53, 1.75)	1.73	(0.84, 3.58)	2.30	(1.03, 5.14)*
Other race	0.25	(0.13, 0.46)**	0.23	(0.12, 0.43)**	0.93	(0.38, 2.29)	0.70	(0.29, 1.68)
< poverty	1.11	(0.74, 1.67)	1.09	(0.73, 1.63)	0.42	(0.23, 0.75)**	0.37	(0.21, 0.63)**
< 1-2x poverty	0.89	(0.59, 1.36)	0.89	(0.58, 1.38)	0.47	(0.29, 0.77)**	0.47	(0.27, 0.80)**
Calories (100s)	1.01	(0.99, 1.04)	1.01	(0.99, 1.04)	1.00	(0.98, 1.03)	1.01	(0.99, 1.03)
Smoker	0.51	(0.35, 0.73)**	0.49	(0.33, 0.71)**	0.39	(0.27, 0.56)**	0.36	(0.24, 0.52)**
Device worn (hrs/wk)	0.99	(0.98, 1.00)**	0.99	(0.99, 1.00)*	0.99	(0.98, 1.00)**	0.99	(0.99, 1.00)
Income($1000s)-BG	0.98	(0.98, 0.99)**	0.99	(0.98, 1.00)**	0.99	(0.98, 1.00)	0.99	(0.98, 1.00)
Age(years)-BG	1.00	(0.97, 1.04)	1.00	(0.96, 1.03)	1.05	(1.01, 1.09)**	1.05	(1.01, 1.09)**
Black-BG	1.26	(0.54, 2.92	1.17	(0.52, 2.63)	0.60	(0.23, 1.54)	0.56	(0.19, 1.63)
Hawaiian-Pacific Islander-BG	2.14	(<0.01, >999)	3.79	(<0.01, >999)	<0.01	(<0.01, 40)	<0.01	(<0.01, 5.42)
Asian-BG	0.27	(0.03, 4.81)	0.21	(0.01, 3.20)	0.05	(0.00, 1.06)*	0.03	(0.00, 0.50)*
Hispanic-BG	1.16	(0.40, 3.36)	1.11	(0.41, 3.05)	1.22	(0.38, 3.94)	1.34	(0.39, 4.60)
Walkability/bikeability variables								
Density (1000s /sq. mile)-BG	1.00	(0.98, 1.03)	1.01	(0.98, 1.04)	1.00	(0.98, 1.02)	1.00	(0.98, 1.03)
Housing age (years)-BG	1.00	(0.99, 1.02)	1.01	(0.99, 1.02)	0.99	(0.98, 1.01)	0.99	(0.98, 1.01)
Walk to work-BG	0.00	(<0.01, 0.17)**	0.01	(<0.01, 0.27)	1.29	(0.03, 48.59)	1.82	(0.04, 81.22)
Bike to work-BG	<0.01	(<0.01, 111)	0.01	(<0.01, 401.)	<0.01	(<0.01, 0.12)*	<0.01	(<0.01, .01)**
Physical activity								
MVPA minutes./day			0.97	(0.96, 0.98)**			0.98	(0.97, 0.98)**
Pseudo-R2	0.16		0.18		0.12		0.17	

** $p<0\ .01$,

* $p<0\ .05$

Note: Boldface indicates significance.

BG, block group