

Active Commuting and Cardiovascular Disease Risk

The CARDIA Study

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Background: There is little research on the association of lifestyle exercise, such as active commuting (walking or biking to work), with obesity, fitness, and cardiovascular disease (CVD) risk factors.

Methods: This cross-sectional study included 2364 participants enrolled in the Coronary Artery Risk Development in Young Adults (CARDIA) study who worked outside the home during year 20 of the study (2005-2006). Associations between walking or biking to work (self-reported time, distance, and mode of commuting) with body weight (measured height and weight); obesity (body mass index [BMI], calculated as weight in kilograms divided by height in meters squared, ≥ 30); fitness (symptom-limited exercise stress testing); objective moderate-vigorous physical activity (accelerometry); CVD risk factors (blood pressure [oscillometric systolic and diastolic]); and serum measures (fasting measures of lipid, glucose, and insulin levels) were separately assessed by sex-stratified multivariable linear (or logistic) regression modeling.

Results: A total of 16.7% of participants used any means of active commuting to work. Controlling for age, race,

income, education, smoking, examination center, and physical activity index excluding walking, men with any active commuting (vs none) had reduced likelihood of obesity (odds ratio [OR], 0.50; 95% confidence interval [CI], 0.33-0.76), reduced CVD risk: ratio of geometric mean triglyceride levels ($\text{trig}_{\text{active}}/\text{trig}_{\text{nonactive}}=0.88$ (95% CI, 0.80 to 0.98); ratio of geometric mean fasting insulin ($\text{FI}_{\text{active}}/\text{FI}_{\text{nonactive}}=0.86$ (95% CI, 0.78 to 0.93); difference in mean diastolic blood pressure (millimeters of mercury) ($\text{DBP}_{\text{active}}-\text{DBP}_{\text{nonactive}}=-1.67$ (95% CI, -3.20 to -0.15); and higher fitness: mean difference in treadmill test duration (in seconds) in men ($\text{TT}_{\text{active}}-\text{TT}_{\text{nonactive}}=50.0$ (95% CI, 31.45 to 68.59) and women ($\text{TT}_{\text{active}}-\text{TT}_{\text{nonactive}}=28.77$ (95% CI, 11.61 to 45.92).

Conclusions: Active commuting was positively associated with fitness in men and women and inversely associated with BMI, obesity, triglyceride levels, blood pressure, and insulin level in men. Active commuting should be investigated as a modality for maintaining or improving health.

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BECAUSE OF ITS FLEXIBILITY and accessibility,^{1,2} walking is generally reported as the most popular leisure-time physical activity for adults³⁻⁵ and has been specifically promoted as a targeted activity to achieve national physical activity recommendations.^{1,6} For most adults, walking 60 minutes per day at a brisk pace is sufficient to meet the Institute of Medicine's physical activity guidelines for avoiding weight gain.^{7,8} One potentially effective means of increasing physical activity is through alternative, nonleisure forms of physical activity such as active commuting (walking or biking to work).

Selected research has suggested an inverse relationship between leisure-time walking and adiposity^{9,10} and cardiovascular disease (CVD) risk factors.¹¹⁻¹⁴ A re-

cent meta-analysis¹⁵ showed modest reductions in cardiovascular outcomes related to active commuting, but most of these studies were conducted in Scandinavian samples. The frequency of active commuting is likely to vary by region. Furthermore, the prevalence of obesity and CVD risk factors is higher in the United States than in Scandinavia. In addition, many previous analyses have not included detailed behavioral and clinical control variables that would permit investigations of whether active commuting has an independent effect on cardiovascular health. Thus, research is needed in US population-based cohorts with rich behavioral data and clinically measured CVD risk factors.

We used population-based data from the Coronary Artery Risk Development in Young Adults (CARDIA) study to exam-

ine the association between active commuting (defined as walking or biking to work) with obesity, fitness, and CVD risk factors (blood pressure [BP] and lipid, blood glucose, and insulin levels) to understand whether active commuting is a feasible target for maintaining or improving health. We hypothesized that active commuting is positively associated with lower obesity, higher fitness, and a favorable CVD risk factor profile.

METHODS

SETTING AND PARTICIPANTS

The CARDIA study is a population-based prospective epidemiologic study of the determinants and evolution of CVD risk factors among young adults. At baseline (1985-1986), 5115 eligible participants, aged 18 to 30 years, were enrolled with balance by race, sex, education (high school or less and more than high school), and age (18-24 years and 25-30 years) from the populations of Birmingham, Alabama; Chicago, Illinois; Minneapolis, Minnesota; and Oakland, California. Specific recruitment procedures are described elsewhere.¹⁶ Six follow-up examinations were conducted over 20 years. We used data from the year-20 (2005-2006) examination, with the year-20 retention rate for surviving cohort members of 72%.

From the initial 3549 study participants at year 20, we excluded 1 transgendered respondent (n=1) and women who were pregnant at the time of examination (n=6). We further excluded participants who reported that they did not work outside of the home (n=507) or for whom data on work outside of the home were missing (n=567) and those missing outcome or covariate data (n=104). The final analysis sample included 2364 individuals with complete exposure, outcome, and covariate data. Among those meeting inclusion criteria, white individuals, nonsmokers, and those with high income, education, and physical activity levels were more likely to have complete data and thus were included in analysis. Missing data also varied by study site, with those in Minneapolis less likely to have complete data. This secondary data analysis was approved by the CARDIA steering committee and the institutional review board of University of North Carolina at Chapel Hill (UNC-CH).

EXPOSURE MEASURE: ACTIVE COMMUTING

At the year-20 examination, participants reported (in minutes and miles) how long it takes to get from home to their place of work and the percentage of the trip taken by car, public transportation (bus, train, subway), walking, or bicycling. Active commuting was defined as any walking or biking during the trip from home to work.

OUTCOME MEASURES

BMI and Obesity

Measurements of weight and height, with participants in light clothing and without shoes, were obtained according to standardized protocol described previously.¹⁷ Body mass index (BMI) was calculated as weight in kilograms divided by height in meters squared, and obesity was classified as a BMI of at least 30.0.

Leisure Time and Occupational Physical Activity

At each examination, self-reported physical activity was ascertained by an interviewer-administered questionnaire designed

for CARDIA. Participants were asked about the frequency of participation in 13 different physical activity (PA) categories (8 vigorous and 5 moderate [VPAs and MPAs, respectively]) of recreational sports, exercise, leisure, and occupational activities over the previous 12 months. The VPAs included running, racquet sports, bicycling faster than 10 miles per hour, swimming, vigorous exercise classes, sports (eg, basketball, football), heavy lifting, carrying or digging on the job, and home activities such as snow shoveling or lifting heavy objects. The MPAs included nonstrenuous sports (eg, softball), walking, bowling or golf, home maintenance (eg, gardening or raking), and calisthenics. Because participants were not asked explicitly about duration of activity, PA scores are expressed in exercise units (EU), from which duration can be estimated.¹⁸ Scores were computed by multiplying the intensity of the activity by the number of months of participation, weighted by a factor proportional to lesser or greater frequency and duration. Separate scores were obtained for VPAs and MPA. The 2 subscores were summed for a total PA score. As an example, a score of 100 EU is roughly equivalent to participation in a VPA 2 or 3 hours per week for 6 months of the year, calculated as $[6 \text{ METs} \times (3 \times 6 \text{ months of high volume activity})]$, where MET indicates metabolic equivalent. The reliability and validity of the instrument is comparable with other activity questionnaires.¹⁸

Using the PA scoring algorithm, we created 2 PA measures. First, we created a specific leisure-walking score derived from walking items in the PA questionnaire as described. We used the continuous walking score, ranging from 0 to 144 EU, to categorize 12-month walking patterns at 3 METs defined as multiples of the resting metabolic rate: none (0 EU), intermittent (1-143 EU), and regular (144 EU, approximating walking ≥ 4 h/wk over a 12-month period) to capture participants with no, moderate, and high levels of walking. Second, we created a PA score that excluded walking, which was dichotomized into low (below the median) and high. This "non-walking" activity variable was used as a control variable in our multivariable regression models to statistically control for PAs other than walking for transit or leisure in models using active transit PA exposures.

Accelerometer-Measured PA

Total daily minutes of MPA and VPA were obtained from at least 4 days of accelerometer recordings. The MPA cut points were established during a treadmill walking session using Freedson cut points (1952-5725 counts/min). Participants were instructed to wear the accelerometer (model 7164; ActiGraph, Pensacola, Florida) around the waist for 7 days, except when sleeping, bathing, or engaging in water activities. The epoch was set at 1 minute, and periods of nonwear were identified by 60 or more consecutive zero counts. At least 4 days of valid data (≤ 720 minutes of inactive time) were required for inclusion in analyses. The MPA minutes per day were dichotomized (< 24.0 and ≥ 24.1 min/d), equivalent to the recommended 5 MPA bouts/wk and examined as a CVD-related health behavior (outcome). The mean accelerometer-measured minutes per day of VPA were dichotomized into meeting (vs not meeting) VPA recommendations and used to exclude those meeting VPA recommendations (n=102 men and 98 women of those with valid accelerometer data) in models examining accelerometer-measured MPA. The rationale for the exclusion was to tie findings directly with the recommendation for MPA.^{19,20}

Treadmill Fitness Test Duration

A symptom-limited maximal Graded Exercise Test was administered using a modified Balke protocol,²¹ including nine

2-minute stages of increasing difficulty with participants encouraged to exercise to exhaustion, followed by a recovery period at a speed of 3.2 km/h at 0% grade. Fitness was indicated by the treadmill test duration in seconds. Primary exclusion criteria for exercise testing included a resting systolic or diastolic BP (SBP or DBP) measurement greater than 160 or greater than 100 mm Hg, respectively, or being febrile at time of examination.

Lipid, Glucose, and Insulin Measurements

Samples of blood lipids, glucose, and insulin were collected according to standardized CARDIA protocols and were processed at central laboratories as described previously.²²⁻²⁵ Individuals fasting for less than 8 hours were excluded from these analyses. Insulin was measured by radioimmunoassay.²⁴ We created the following measures: high-density lipoprotein cholesterol (HDL-C), low-density lipoprotein cholesterol (LDL-C), and triglyceride levels (all 3 measures reported in milligrams per deciliters) and exclude participants reporting cholesterol-lowering medications (n=194), and fasting glucose and fasting insulin levels (both measures reported in milligrams per deciliters) and exclude participants reporting diabetes medications (n=85).

BP Measurements

Three SBP and DBP measurements were obtained by a trained technician using a standard automated BP measurement monitor (model HEM907XL; Omron, Bannockburn, Illinois) after a 5-minute seated rest. The mean of the second and third measurements was used for analysis. Participants were asked to fast for at least 12 hours and not to smoke or engage in heavy PA for at least 2 hours prior to the measurement. We used SBP and DBP measurements calibrated to be comparable with random-zero sphygmomanometers used in prior CARDIA examination periods (SBP calibrated to the random zero level was estimated as $3.74 + 0.96 \times$ the Omron value; DBP as $1.30 + 0.97 \times$ the Omron value) and reported in milligrams per deciliter and excluding participants reporting use of BP-lowering medications (n=374).

Control Variables

Sociodemographic and behavioral characteristics were measured by self- and interviewer-administered questionnaires. Age (years), race (black or white), income tertiles (<\$50 000, \$50 000-\$99 999, or \geq \$100 000), years of education (high school or less, any college, graduate school or professional training), and clinic site (Birmingham, Chicago, Minneapolis, or Oakland) were used as control variables in all statistical models. Smoking status was classified as never smoker, former smoker, or current smoker, and alcohol intake was classified as no consumption, 12 mL/d or less (sample median), or more than 12 mL/d).

STATISTICAL ANALYSIS

Statistical analyses were conducted using Stata software (version 9.2; StataCorp, College Station, Texas). Descriptive statistics were computed for commuting patterns, nonwalking PA, smoking, alcohol consumption, and sociodemographic factors and presented by active vs nonactive commuting (any walking or biking during the trip from home to work) and sex. Percentages were calculated for categorical variables. Continuous variables were calculated either as means and standard errors or median and interquartile range (for skewed measures).

Associations between walking or biking to work and BMI, fitness, and CVD risk factors were separately assessed by sex-stratified multivariate regression (linear, logistic, or multinomial logistic) modeling. If necessary, outcome variables were transformed or categorized based on their sample distribution. Skewed variables were natural log transformed to achieve approximate normality or categorized into ordinal variables if transformation was not adequate. Leisure walking and accelerometer-measured leisure MPA were examined as categorical variables to explicitly examine policy-relevant categories of PA. All models adjusted for sociodemographics (age, race, income, years of education, and examination center). Leisure-time walking models also adjusted for nonwalking PA score (to hold all nonwalking PAs constant). Accelerometer-measured MPA models excluded those meeting accelerometer-measured VPA recommendations (>8 min/d). Two sets of fitness models—obesity and BMI—were conducted: model 1 adjusted for sociodemographics and model 2 adjusted for sociodemographics and health-related behaviors (alcohol consumption, smoking, and nonwalking PA score). In addition, models for lipid levels, BP, and fasting glucose and insulin measurements controlled for BMI to examine BMI as a potential mediator.

Measures of effect varied across models, depending on the outcome measure. For categorical outcomes, adjusted odds ratios were used. For continuous natural log-transformed outcomes, we calculated the ratio of the outcome in its reported scale for those who actively commute relative to those who do not. For continuous untransformed outcome, we calculated the difference in outcome between those who actively commute vs those who do not.

Interactions between active commuting and MPAs to VPAs other than walking were tested by including the appropriate cross-product terms in the model and assessing likelihood ratio tests ($P \leq .10$). Final models were stratified by sex. Variables were retained in models if backward elimination resulted in a greater than 10% change in the estimated effect measures or if variables were conceptually relevant (eg, control for clinic site).

RESULTS

DESCRIPTIVE CHARACTERISTICS

Of the 2364 respondents who worked outside of the home, 16.7% of the sample (men, 18.0%; women, 15.6%) used any means of active commuting to work. In both sexes, active commuters were generally of higher education levels, with variation across examination center (particularly low active commuting was found in Birmingham). Among women, active commuting was higher among whites and those with higher nonwalking PA levels. Among men, active commuting was higher in those with greater alcohol intake (**Table 1**).

Patterns of commuting behavior, shown in **Table 2**, were reported for the total trip to work (eg, participants reported the percentage of trip made by walking, bike, car, and public transportation). Average miles and minutes of the commute to work varied between active and nonactive commuters, with medians of 5 miles (for men and women) and 20 and 17 minutes (for men and women, respectively) for those who actively commuted to work (distance and minutes of commuting may not correspond owing to combined modes of transportation). Considerably higher proportions of participants used walking vs biking for their

Table 1. Descriptive Statistics for Participants at Examination Year 20 (2005-2006) of the CARDIA Study, by Sex and Commuting Status^a

Characteristic	Men		Women	
	Nonactive Commuters (n=873)	Active Commuters (n=192)	Nonactive Commuters (n=1096)	Active Commuters (n=203)
Age, mean (SE), y	45.2 (0.1)	45.3 (0.2)	45.1 (0.1)	45.6 (0.3)
Race				
Black	39.3 (1.7)	35.4 (3.5)	50.5 (1.5) ^b	37.9 (3.4) ^b
White	60.7 (1.7)	64.6 (3.5)	49.5 (1.5) ^b	62.1 (3.4) ^b
Education				
≤High school	38.8 (1.7) ^b	32.8 (3.4) ^b	36.2 (1.5) ^b	26.1 (3.1) ^b
Any college	42.6 (1.7) ^b	34.4 (3.4) ^b	44.0 (1.5) ^b	50.7 (3.5) ^b
Graduate school/professional training	18.6 (1.3) ^b	32.8 (3.4) ^b	19.8 (1.2) ^b	23.2 (3.0) ^b
Income tertile, \$				
1 (<50 000)	23.4 (1.4)	27.6 (3.2)	36.0 (1.5)	37.4 (3.4)
2 (50 000-99 000)	37.9 (1.6)	35.4 (3.5)	38.2 (1.5)	34.0 (3.3)
3 (≥100 000)	38.7 (1.6)	37.0 (3.5)	25.8 (1.3)	28.6 (3.2)
Examination center				
Birmingham, Alabama	29.8 (1.5) ^b	7.3 (1.9) ^b	25.2 (1.3) ^b	4.9 (1.5) ^b
Chicago, Illinois	20.6 (1.4) ^b	31.8 (3.4) ^b	21.4 (1.2) ^b	27.1 (3.1) ^b
Minneapolis, Minnesota	24.6 (1.5) ^b	30.7 (3.3) ^b	22.7 (1.3) ^b	30.5 (3.2) ^b
Oakland, California	25.0 (1.5) ^b	30.2 (3.3) ^b	30.7 (1.4) ^b	37.4 (3.4) ^b
Smoking status				
Never	65.4 (1.6)	67.2 (3.4)	60.7 (1.5)	61.6 (3.4)
Former	17.5 (1.3)	17.7 (2.8)	22.2 (1.3)	21.7 (2.9)
Current	17.1 (1.3)	15.1 (2.6)	17.2 (1.1)	16.7 (2.6)
Alcohol use				
None	39.5 (1.7) ^b	26.0 (3.2) ^b	52.5 (1.5)	45.3 (3.5)
≤12 mL/d ^c	22.7 (1.4) ^b	31.8 (3.4) ^b	26.2 (1.3)	27.1 (3.1)
>12 mL/d ^c	37.8 (1.6) ^b	42.2 (3.6) ^b	21.4 (1.2)	27.6 (3.1)
PA other than walking, sex-specific tertile ^d				
1	29.7 (1.5)	28.1 (3.3)	31.1 (1.4) ^b	24.1 (3.0) ^b
2	35.9 (1.6)	33.3 (3.4)	35.3 (1.4) ^b	30.0 (3.2) ^b
3	34.5 (1.6)	38.5 (3.5)	33.6 (1.4) ^b	45.8 (3.5) ^b

Abbreviations: CARDIA, Coronary Artery Risk Development in Young Adults; PA, physical activity.

^aLimited to respondents with no missing covariates. Active commuting was defined as any walking or biking during the trip from home to work. Data are given as percentage (standard error).

^bStatistically different ($P < .05$) between active commuters vs nonactive commuters, within sex (χ^2).

^cCut point is equal to the median value among those with values greater than zero.

^dIndex derived from a standard PA questionnaire.

active commuting. There was variation across modes of transit, even for those who used active means of commuting, with the highest proportions of commuters using cars for some portion of their commute. Of note are low overall rates of active commuting.

Likelihood of leisure walking was positively related to active commuting, with strongest association seen for the regular walker vs nonwalker comparison (**Table 3**). Similarly, among those meeting VPA recommendations, accelerometer-measured MPA was positively related to active commuting, although statistically significant for women only ($P = .002$).

Treadmill fitness test duration (in seconds) was higher among men and women who actively vs nonactively commuted to work in models with adjustment for sociodemographics only (model 1) and then adding smoking, alcohol, and leisure PA, excluding walking (model 2) (**Table 4**). Similarly, BMI and likelihood of obesity were lower among men who were active (vs nonactive) commuters. When analyses were restricted to those living within 2 miles of their place of work, results were similar (with the exception of women for BMI and obesity).

Table 5 contrasts associations between active commuting and CVD risk factors in 2 models: model 1, adjusting for sociodemographics; and model 2, adjusting for model 1 covariates plus smoking, alcohol, and leisure PA. In men, active commuting was inversely associated with triglyceride level, DBP, and fasting insulin level, and positively associated with HDL-C. Results varied depending on statistical adjustment, with HDL-C becoming nonsignificant in model 2 ($P = .18$). Across all outcomes, statistical significance disappeared with BMI adjustment (results not shown). Active commuting was not statistically associated with any CVD risk biomarkers in women (see Table 5 for P values).

COMMENT

Few participants in this population-based cohort reported any walking or biking to work. In men, active commuting was inversely associated with BMI, obesity, triglyceride level, DBP, and fasting insulin and positively associated with walking, HDL-C, and fitness. In women,

Table 2. Commuting Patterns^a at Examination Year 20 (2005-2006) of the CARDIA Study, by Sex and Commuting Status^b

Variable	Men		Women	
	Nonactive Commuters (n=873)	Active Commuters (n=192)	Nonactive Commuters (n=1096)	Active Commuters (n=203)
Miles to work, median (IQR) ^c	14 (7-22) ^d	5 (2-13.5) ^d	10 (5-20) ^d	5 (1-10) ^d
Minutes to work, median (IQR) ^c	20.5 (15-35) ^d	20 (10-40) ^d	20 (15-30) ^d	17 (10-30) ^d
Walked to work, % (SE)	NA ^b	64.1 (3.5) ^b	NA ^b	82.8 (2.7) ^b
Biked to work, % (SE)	NA ^b	49.5 (3.6) ^b	NA ^b	28.1 (3.2) ^b
Method of transportation, %, median (IQR)				
Bike	NA ^b	0 (0-10) ^b	NA ^b	0 (0-1) ^b
Car	100 (100-100) ^d	50 (0-90) ^d	100 (100-100) ^d	50 (0-90) ^d
Public transportation	0 (0-0) ^d	0 (0-32.5) ^c	0 (0-0) ^d	0 (0-50) ^d
Walking	NA ^b	5 (0-22.5) ^b	NA ^b	10 (1-30) ^b

Abbreviations: CARDIA, Coronary Artery Risk Development in Young Adults; IQR, interquartile range; NA, not applicable.

^aActive commuting was defined as any walking or biking during the trip from home to work. Given the very low rates of active commuting, the distribution of these variables includes a substantial proportion of the sample reporting no active commuting (or 0% of the trip made by biking, walking, or public transportation).

^bStatistics were limited to respondents with no missing covariates. Statistics for walking and biking to work are not applicable to nonactive commuters; differences in statistics for walking and biking to work were therefore not tested between active and nonactive commuters.

^cDistance and minutes of commute reported by percentage of trip made by walking, bike, car, public transportation; thus, values are not expected to correspond.

^dStatistically different ($P < .001$) between active commuters vs nonactive commuters, within sex (t test on natural log-transformed variable).

Table 3. Association Between Active Commuting Physical Activity (PA) and 2 Forms of Leisure PA: Walking and Objectively Measured Moderate and Vigorous PA at Examination Year 20 (2005-2006) of the CARDIA Study^a

Outcome	Men		Women	
	Model Effect (95% CI)	P Value	Model Effect (95% CI)	P Value
Leisure walking, mlogit (OR) ^b				
Nonwalker	1 [Reference]		1 [Reference]	
Intermittent vs nonwalker	1.96 (1.25-3.08)	.004	2.82 (1.64-4.86)	<.001
Regular vs nonwalker	3.26 (1.95-5.43)	<.001	5.62 (3.10-10.18)	<.001
Accelerometer-measured leisure moderate PA, logit (OR) ^c				
Meets recommendations	1.16 (0.71-1.90)	.06	1.83 (1.25-2.69)	.002

Abbreviations: CARDIA, Coronary Artery Risk Development in Young Adults; CI, confidence interval; OR, odds ratio.

^aActive commuting was defined as any walking or biking during the trip from home to work. Bold font indicates significant association ($P < .05$).

^bN=1065 men and 1299 women. The ORs obtained multinomial logistic regression models, controlling for age, race, income, education, examination center, and PA index excluding walking (self-report).

^cN=21 men and 930 women. The moderate PA recommendations (≥ 30 min/d on ≥ 5 d/wk) correspond to a mean of $30 \times 5/7 = 21.4$ min/d, within or without moderate PA bouts. The ORs obtained logistic regression models, controlling for age, race, income, education, and examination center, among individuals without accelerometer-measured vigorous PA. Individuals with less than 4 valid accelerometry days were excluded from the study.

walking and treadmill time were positively associated with active commuting. However, statistical associations between active commuting and all CVD risk biomarkers in men disappeared with adjustment for BMI, suggesting that BMI is a potential mediator between active commuting and CVD risk. Results were similar when restricted to those living within a 2-mile distance from their place of work.

Associations were clearer for men, who had relatively higher rates and distance of active commuting, thus suggesting that efforts to increase active commuting in women may be particularly relevant for increasing overall PA. While the association of active commuting with walking behavior and fitness are clear for women, associations between active commuting and measures of CVD risk were less clear for women. The reason for the lack of associations for women could be that women have lower levels of active commuting, or they may have lower intensity of activity during active commuting.

Although the positive association between walking and CVD risk has been well investigated for leisure walking (see, eg, the reviews by Hamer and Chida²⁶ and Murphy et al²⁷), there is less research on the associations with nonleisure forms of PA, such as walking for utilitarian purposes.²⁸ A study of Finnish adults²⁹ observed an inverse association between daily active commuting and ischemic stroke, with the highest risk reduction at greater time in active commuting. Interestingly, in that study, associations were evident only in the pooled sample of men and women (with BMI and other risk factor adjustment), but not in each separately, indicating a relatively modest magnitude of effect. This same research group similarly found reductions in type 2 diabetes mellitus (DM),³⁰ other cardiovascular risk factors,^{31,32} including reductions in mortality among men and women with DM³³ and women with hypertension³⁴ who used active forms of commuting, such as walking or biking. A study in Danish adults observed positive associations between active commuting and HDL-C level and nega-

Table 4. Association Between Active Commuting and Fitness, BMI, and Obesity at Examination Year 20 (2005-2006) of the CARDIA Study^a

Variable	Model Effect Measure	No.	Mean, % (SE)	BMI Model 1, Measure of Effect (95% CI)	P Value	BMI Model 2, Measure of Effect (95% CI)	P Value
Men							
TT duration, seconds ^b	$(TT_{\text{active}}) - (TT_{\text{nonactive}})$	1038	520.3 (136.8)	58.58 (38.67-78.49)	<.001	50.02 (31.45-68.59)	<.001
BMI ^c	$(BMI_{\text{active}})/(BMI_{\text{nonactive}})$	1063	28.7 (5.2)	0.94 (0.92-0.97)	<.001	0.95 (0.92-0.97)	<.001
Obesity ^d	logit (OR)	1063	31.2 (1.4)	0.51 (0.34-0.76)	.001	0.50 (0.33-0.76)	.001
Women							
TT duration, seconds ^b	$(TT_{\text{active}}) - (TT_{\text{nonactive}})$	1250	364.2 (141.4)	34.72 (16.40-53.04)	<.001	28.77 (11.61-45.92)	.001
BMI ^c	$(BMI_{\text{active}})/(BMI_{\text{nonactive}})$	1295	29.4 (7.3)	1.00 (0.97-1.03) ^e	>.99	1.01 (0.97-1.04) ^e	.66
Obesity ^d	logit (OR)	1295	39.1 (1.4)	0.87 (0.62-1.22) ^e	.41	0.91 (0.64-1.29) ^e	.59

Abbreviations: BMI, body mass index (calculated as weight in kilograms divided by height in meters squared); CARDIA, Coronary Artery Risk Development in Young Adults; CI, confidence interval; OR, odds ratio; TT, treadmill test.

^aActive commuting was defined as any walking or biking during the trip from home to work. Model 1 was adjusted for age, race, income, education, and examination center. Model 2 was adjusted for smoking, alcohol consumption, physical activity index excluding walking (self-report), and model 1 variables. Bold font indicates significant association ($P < .05$).

^bDifferences were obtained from linear regression of treadmill fitness test duration on active commuting and control variables.

^cRatios obtained by exponentiation of coefficients from linear regression of natural log-transformed BMI on active commuting and control variables.

^dThe ORs obtained logistic regression of obesity on active commuting and control variables.

^eWhen limiting statistics to participants who reside within 2 miles of their work location estimated associations were similar across sexes and outcomes, with the exception of women: BMI model 1: $(BMI_{\text{active}})/(BMI_{\text{nonactive}}) = 0.93$ (94% CI, 0.86-0.99); BMI model 2: $(BMI_{\text{active}})/(BMI_{\text{nonactive}}) = 0.92$ (95% CI, 0.86-0.99); obesity model 1: OR, 0.47 (95% CI, 0.22-1.01); and obesity model 2: OR, 0.45 (95% CI, 0.20-1.02).

tive associations with LDL-C and triglyceride levels, waist circumference, and BMI.³⁵ This type of work is limited in US samples.

The strengths of this study include extensive CVD risk biomarker data, objective PA measures, detailed active commuting data, and additional measures of leisure PA. Furthermore, most studies relating walking to CVD risk factors do not adequately control for adiposity and leisure PA²⁶ as we have in the present study. Even with these strengths, however, there are limitations. The CARDIA study data are observational in nature, and our results do not imply causality. In addition, the present study is cross-sectional. Yet, our results suggest that any portion of the commute made by walking or biking is important for maintaining or improving health, regardless of the direction of causation. Unfortunately, the low rates of active transit preclude analyses of dose response and thus reduce the power to detect effects. Even using the lowest possible threshold (ie, "any active commuting") to define active commuting, there were favorable associations with several CVD risk factors in men. Thus, associations could be underestimated owing to low variability, and higher levels of active commuting could produce stronger associations with CVD risk factors.

A major limitation is the potential self-selection of active transportation: individuals who are more inclined to be active may be more likely to use active forms of transportation. Indeed, Williams³⁶ has shown that self-selection bias plays a role in the inverse associations between adiposity and walking (leaner individuals selecting to walk greater distances and at higher intensity). Similarly, there is evidence of higher rates of walking among individuals who prefer and live in walkable neighborhoods.³⁷ However, many of the associations in this study remained after controlling for other forms of PA.

We are further limited by self-reported commuting data and other lifestyle factors and cannot completely con-

trol for misreporting, although nondifferential measurement error would tend to bias our results toward the null. Although our active commuting measure has face validity and was related to fitness levels, no psychometric evaluation was conducted.

Although these data do not fully resolve the role of active commuting in health, they contribute information that adds to current thought that additional active commuting would have several benefits. Walking is a particularly good form of activity to target. Among leisure walkers, walking is the sole source of their leisure PA.³⁸ Indeed, adherence to PA recommendations is higher when considering both leisure and nonleisure forms of PA.²⁸ Furthermore, walking can be integrated into other activities beyond leisure into active transportation or commuting³⁹⁻⁴² and overall lifestyle activity.^{1,6-8} Public support for policies that encourage active commuting has been shown, particularly for individuals with experience using active commuting and with positive attitudes toward walking and biking.⁴³ Intervention research to promote active commuting, reviewed by Ogilvie et al,⁴⁴ indicates that most of these interventions consistently report a net increase in proportion of trips by foot and in walking in general. Furthermore, increasing active commuting will have the dual benefits of increasing population health and in reduction of greenhouse gas emissions.⁴⁵ Environmental supports for commuting, such as physical environment⁴⁶⁻⁴⁸ and sociocultural^{46,47} factors, have been shown to promote active forms of commuting.

These findings support previous studies of health benefits of leisure-time walking and extend these findings to active commuting. Future investigation into the link between active commuting and health outcomes should address the amount of commuting needed for positive health benefit. There is a substantial need for development of more precise measures of active commuting. Most important, the use of longitudinal designs to address selectivity and reverse causality is strongly encouraged. Simi-

Table 5. Association Between Active Commuting and CVD Risk Biomarkers at Examination Year 20 (2005-2006) of the CARDIA Study^a

Variable	Model (Effect Measure)	No.	Mean/% (SE)	Model 1, Measure of Effect (95% CI)	P Value	Model 2, Measure of Effect (95% CI)	P Value
Men							
HDL-C level ^b	(HDL-C _{active})/(HDL-C _{nonactive})	883	47.8 (14.2)	1.05 (1.00 to 1.10)	.04	1.03 (0.99 to 1.08)	.18
LDL-C level ^b	(LDL-C _{active})/(LDL-C _{nonactive})	862	116.9 (31.7)	0.99 (0.94 to 1.04)	.60	0.99 (0.93 to 1.04)	.58
Trig level ^b	(trig _{active})/(trig _{nonactive})	883	127.0 (97.5)	0.88 (0.80 to 0.98)	.01	0.88 (0.80 to 0.98)	.02
DBP level ^{c,d}	(DBP _{active}) – (DBP _{nonactive})	913	71.6 (9.2)	-1.54 (-3.07 to -0.01)	.05	-1.67 (-3.20 to -0.15)	.03
SBP level ^{c,d}	(SBP _{active}) – (SBP _{nonactive})	913	116.9 (11.3)	-1.39 (-3.29 to 0.52) ^d	.15	-1.60 (-3.51 to 0.32) ^d	.10
FG level ^e	(FG _{active})/(FG _{nonactive})	965	99.9 (17.4)	0.98 (0.96 to 1.00)	.12	0.98 (0.96 to 1.01)	.16
FI level ^e	(FI _{active})/(FI _{nonactive})	964	14.5 (9.4)	0.84 (0.77 to 0.92)	<.001	0.86 (0.78 to 0.93)	<.001
Women							
HDL-C level ^b	(HDL-C _{active})/(HDL-C _{nonactive})	1120	60.1 (16.0)	1.02 (0.98 to 1.06)	.41	1.01 (0.97 to 1.06)	.53
LDL-C level ^b	(LDL-C _{active})/(LDL-C _{nonactive})	1117	108.5 (29.2)	1.01 (0.96 to 1.06)	.68	1.01 (0.97 to 1.06)	.59
Trig level ^b	(trig _{active})/(trig _{nonactive})	1120	90.9 (60.1)	1.02 (0.95 to 1.11)	.55	1.04 (0.96 to 1.12)	.39
DBP level ^{c,d}	(DBP _{active}) – (DBP _{nonactive})	1076	69.8 (10.7)	-0.18 (-1.84 to 1.47)	.83	-0.15 (-1.81 to 1.51)	.86
SBP level ^{c,d}	(SBP _{active}) – (SBP _{nonactive})	1076	111.4 (13.7)	0.93 (-1.20 to 3.07)	.39	0.74 (-1.39 to 2.87) ^e	.50
FG level ^e	(FG _{active})/(FG _{nonactive})	1143	94.2 (16.1)	1.00 (0.98 to 1.02)	.85	1.00 (0.98 to 1.02)	.99
FI level ^e	(FI _{active})/(FI _{nonactive})	1143	13.4 (8.3)	1.00 (0.92 to 1.08)	.93	1.00 (0.93 to 1.09)	.93

Abbreviations: BP, blood pressure; CARDIA, Coronary Artery Risk Development in Young Adults; CI, confidence interval; CVD, cardiovascular disease; DBP, diastolic blood pressure; FG, fasting glucose; FI, fasting insulin; HDL-C, high-density lipoprotein cholesterol; LDL-C, low-density lipoprotein cholesterol; SBP, systolic blood pressure; trig, triglycerides.

^aActive commuting was defined as any walking or biking during the trip from home to work. Model 1 was adjusted for age, race, income, education, and examination center. Model 2 was adjusted for smoking, alcohol consumption, physical activity index excluding walking (self-report), and model 1 variables. Bold font indicates significant association ($P < .05$).

^bRatios obtained by exponentiation of coefficients from linear regression of natural log-transformed lipid measure on active commuting and control variables. Excludes individuals reporting cholesterol-lowering medications or who fasted less than 8 hours prior to blood draw.

^cDifferences obtained from linear regression of BP measure on active commuting and control variables. Excludes individuals reporting BP-lowering medications.

^dWhen limiting to participants who reside within 2 miles of their work location, estimated associations were similar across sexes and outcomes, with the exception of SBP; men, model 1: (SBP_{active}) – (SBP_{nonactive}) = 3.92 (95% CI, -0.74 to 8.59), model 2: (SBP_{active}) – (SBP_{nonactive}) = 4.40 (95% CI, -0.24 to 9.04); women, significant interaction with physical activity, high physical activity: (SBP_{active}) – (SBP_{nonactive}) = 2.39 (95% CI, -0.50 to 5.29), low physical activity: (SBP_{active}) – (SBP_{nonactive}) = -1.17 (95% CI, -4.26 to 1.92).

^eRatios obtained by exponentiation of coefficients from linear regression of natural log-transformed fasting insulin and glucose measures on active commuting and control variables. Excludes individuals reporting diabetes medications or who fasted less than 8 hours prior to blood draw.

larly, research aimed at unraveling the selectivity in active commuting behaviors and understanding whether those who choose to actively commute are healthier and more active is of utmost importance.

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