Published in final edited form as:
Am J Prev Med. 2012 June ; 42(6): 571–578. doi:10.1016/j.amepre.2012.02.020.

Commuting Distance, Cardiorespiratory Fitness, and Metabolic Risk

Christine M. Hoehner, PhD, MSPH, **Carolyn E. Barlow, MS**, **Peg Allen, MPH**, and **Mario Schootman, PhD**
Division of Public Health Sciences (Hoehner), the Division of Health Behavior Research (Schootman), The Alvin J. Siteman Cancer Center (Hoehner, Schootman), The Brown School of Social Work (Allen), Washington University in St. Louis, St. Louis, Missouri; The Cooper Institute (Barlow), Dallas, Texas

Abstract

Background—Limited evidence exists on themetabolic and cardiovascul ar risk correlates of commuting by vehicle, a habitual form of sedentary behavior.

Purpose—To examine the association between commuting distance, physical activity, cardiorespiratory fitness (CRF), and metabolic risk indicators.

Methods—This cross-sectional study included 4297 adults who had a comprehensive medical examination between 2000 and 2007 and geocoded home and work addresses in 12 Texas metropolitan counties. Commuting distance was measured along the road network. Outcome variables included weekly MET-minutes of self-reported physical activity, CRF, BMI, waist circumference, triglycerides, plasma glucose, high-density lipoprotein (HDL) cholesterol, systolic and diastolic blood pressure, and continuously measured metabolic syndrome. Outcomes were also dichotomized using established cut-points. Linear and logistic regression models were adjusted for sociodemographic characteristics, smoking, alcohol intake, family history of diabetes, and history of high cholesterol, as well as BMI and weekly MET-minutes of physical activity and CRF (for BMI and metabolic risk models). Analyses were conducted in 2011.

Results—Commuting distance was negatively associated with physical activity and CRF and positively associated with BMI, waist circumference, systolic and diastolic blood pressure, and continuous metabolic score in fully adjusted linear regression models. Logistic regression analyses yielded similar associations; however, of the models with metabolic risk indicators as outcomes, only the associations with elevated blood pressure remained significant after adjustment for physical activity and CRF.

Conclusions—Commuting distance was adversely associated with physical activity, CRF, adiposity, and indicators of metabolic risk.

Address correspondence to: Christine Hoehner, PhD, MSPH, Division of Public Health Sciences Washington University School of Medicine, 660 S. Euclid Ave., Campus Box 8100, St. Louis, MO 63110. hoehnerc@wudosis.wustl.edu.

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

Introduction

Physical inactivity is a leading public health issue in the U.S.[1] and internationally[2] and has increased over time.[3] Accumulating evidence suggests that time spent sitting has adverse effects on cardiovascular and metabolic health, distinct from time spent being physically active.[4–6] Health risks associated with sedentary behavior may be attributed to the physiologic effects of muscle inactivity on glucose uptake, cardiac function, and lipid metabolism, as well as sedentary behavior displacing light-to-moderate activity and thus reducing energy expenditure.[7–9]

Although most research on sedentary behavior has focused on TV viewing, the metabolic and cardiovascular health impacts of long commutes by automobile are less well understood.[5, 10–15] Travel by motorized vehicle is the most common light activity reported in the U.S.,[16] and commuting to work is an especially important purpose of travel to study because it is part of people's routine and constitutes the largest share of annual vehicle miles traveled per household in the U.S.[17]

Although active commuting has documented health benefits,[18–19] it may be infeasible for many adults. Understanding the health effects of passive commuting is also important given that commuting by vehicle is prevalent and has increased in recent decades. In the U.S. between 1960 and 2000, the number of workers commuting by private vehicle increased from 41.4 million to 112.7 million.[20–21] Moreover, average commuting distances and time by private vehicle have increased from 8.9 miles and 17.6 minutes in 1983 to 12.1 miles and 22.5 minutes in 2001.[17] These trends parallel population shifts from urban to suburban settings, with the proportion of people living in suburbs having increased from 23% to 50% between 1950 and 2000.[20]

This study examined the association between commuting distance from home to work with CRF, physical activity levels, and metabolic risk indicators among men and women without known diabetes. By examining biomarkers and using objective home-to-work route distance, this study illuminates possible mechanisms for the increased risk of cardiovascular disease death associated with time driving in an automobile among men in this study population.[15]

Methods

Study Design and Population

The study population included participants in the Cooper Center Longitudinal Study (CCLS) who were seen at the Cooper Clinic in Dallas TX for a preventive medical examination. Most patients were referred by their personal physician or employer, or were self-referred. Patients signed an informed consent for the clinical examinations. This study was approved by the IRBs of The Cooper Institute and Washington University.

The current cross-sectional analysis, conducted in 2011, included data from the most recent examination of participants aged 18–90 years who had a maximal treadmill test between January 2000 and June 2007. In addition, the study included employed participants with nonmissing geocodable home and work addresses in 11 counties of the Dallas–Fort Worth TX metropolitan area and Travis County in the Austin TX metropolitan area where the majority of participants resided. Participants were excluded if they reported >6 weeks of sick days in the past year, had missing data on the primary outcomes or covariates of interest, reported a personal history of heart attack, stroke, or diabetes, or were pregnant. Participants who reported home addresses as work addresses were also excluded.

Subanalyses with waist circumference excluded 991 participants with missing data on this variable.

Data Collection

Clinical examination—Body composition, laboratory measurements, and assessment of CRF by a maximal exercise treadmill test were performed at the clinical examination. In addition, patients completed a detailed medical history questionnaire consisting of demographic, health habits, and health history information.

Geocoding addresses—The home and work addresses of patients living in Texas who had exams with a maximal treadmill test between January 2000 and July 2007 (n=16,939) were geocoded by a commercial firm. Eighty-nine percent of home and 75% of work addresses were assigned to a latitude/longitude corresponding to the location of the address. All other addresses were excluded due to low positional accuracy (i.e., geocoded to census block group or census tract, ZIP code centroid, or post office box). Of the successfully geocoded addresses, 7181 had home and work addresses within the study area.

Measures

Commuting distance—Shortest distance from home to work (in miles) along the road network was calculated in ArcGIS 9 software. Commuting distance in miles was treated both continuously and categorically based on meaningful cut-points in order to explore nonlinear relationships: 1–5, 6–10, 11–15, 16–20, and >20 miles. Commuting mode was unknown but likely by motorized private vehicles given travel patterns in this region.[22]

Health outcomes—Outcome measures of interest included physical activity, CRF, BMI, and metabolic risk variables (waist circumference, fasting triglycerides, fasting plasma glucose, high-density lipoprotein (HDL) cholesterol, systolic and diastolic blood pressure, and metabolic syndrome). Self-reported weekly participation in moderate-to-vigorous physical activity over the past 3 months was assessed using a validated self-administered medical history questionnaire for walking, jogging/running, treadmill activity, outdoor or stationary bicycling, swimming, aerobic dance or floor exercises, vigorous sports and exercise, and an open-ended item about other activity.[23,24] Weekly minutes of moderate-to-vigorous physical activity were derived by multiplying frequency and duration for each of these types of physical activity, among those who had nonmissing data for all activities or >0 minutes for at least one of the activities. Weekly minutes of activity were weighted by each activity's assigned METs to yield weekly MET-minutes of moderate-to-vigorous physical activity.[25] Dichotomous variables were created to represent meeting U.S. public health recommendations (≥500 vs <500 MET-minutes/week).[1]

Cardiorespiratory fitness was determined by a maximal exercise treadmill test using a modified Balke protocol.[26–29] Patients were encouraged to give a maximal effort, and the test end point was volitional exhaustion or termination by the physician for medical reasons. The speed and elevation of the final minute of the treadmill test were used to convert treadmill performance to METs.[30] Time on treadmill with this protocol is highly correlated with maximal volume of oxygen uptake (r =0.94 in women[31] and r =0.92 in men[32]). CRF was grouped as fit or unfit on the basis of the upper 20% and lower 80% of the age-standardized CRF distribution.[28]

The standard measure for BMI was used. Obesity was defined as having a BMI ≥30. Waist circumference was measured at the level of the umbilicus with a plastic anthropometric tape. All clinical measurements were made in the morning following a fast of at least 12 hours. A fasting blood sample was obtained by venipuncture, and serum triglyceride, HDL cholesterol, and plasma glucose levels were assayed using standardized techniques at the Cooper Clinic Laboratory. Blood pressure measurements were obtained with a mercury sphygmomanometer using auscultatory methods.

Metabolic syndrome was defined according to established criteria,[33] which consists of three or more of the following traits: central obesity (waist circumference ≥102 cm among men and ≥88 cm among women); elevated triglycerides (≥150 mg/dl); reduced HDL-cholesterol (<40 mg/dl among men and <50 mg/dl among women); elevated blood pressure (systolic ≥130 mmHg or diastolic ≥85 mmHg or self-reported high blood pressure); or elevated fasting plasma glucose (≥100 mg/dl).[33] A validated continuous metabolic score was calculated, as previously described.[34] The mean metabolic score was 0±1.41 in men and 0±1.41 in women. This score has high validity[34] and has been associated with sedentary behavior, muscular strength, and aerobic fitness in other studies.[35,36]

Covariates—Information on sociodemographic factors, cigarette smoking, alcohol consumption, personal history of high blood pressure and high cholesterol, and family history of diabetes were self-reported and coded as categoric variables (Table 1). Alcohol consumption was coded using evidence-based cut-points as none, light (≤3 units/week), moderate (3–14 units/week for men; 3–7 units/week for women), and heavy (>14 units/week for men; >7 units/week for women).[37]

Statistical Analysis

Statistical analyses were conducted using SAS Statistical Software 9.3. Multiple linear regression analysis was used to examine the association of commuting distance with physical activity, CRF, BMI, and metabolic risk variables. The natural logarithm of triglycerides was used in regression analyses to account for its skewness. In addition, multiple logistic regression analysis was used to examine dose–response effects between categories of commuting distance and clinically meaningful cut-points of the outcomes.

Two models were examined for each statistical analysis. Model A was adjusted for age, gender, education, marital status, children in home, smoking status, alcohol intake, family history of diabetes, BMI (for all models except those with BMI, waist circumference, or metabolic syndrome as the outcomes), personal history of high cholesterol (only for the models with triglycerides and HDL cholesterol as outcomes), and personal history of high blood pressure (only for the models with systolic and diastolic blood pressure as outcomes). Model B was additionally adjusted for CRF and weekly MET-minutes of moderate-to-vigorous physical activity to examine how adjustment of these indicators of total physical activity attenuated relations with commuting distance.

Results were reported as unstandardized β coefficients for the linear regression models and as ORs for the logistic regression models. A priori defined interactions of commuting distance with gender, age, physical activity participation, and BMI were assessed. Significance was set at $p<0.05$. Adjusted R^2 assessed model fit in multiple linear regression analyses. Tests for linear association of the ORs were computed by the Mantel extension test.[38]

Results

Of the 7181 participants with geocoded addresses in the study areas, exclusions were made based on the following criteria: working from home (n=700), being unemployed, a housewife, student or fully retired (n=62), being sick for more than 6 weeks in the past year (n=1870), history of heart attack (n=38), stroke (n=23), or diabetes (n=121); or currently pregnant (n=3). Of the remaining 6225 participants, 1003 were excluded with missing data on at least one outcome variable. An additional 925 were excluded with missing data on marital status, history of high cholesterol, smoking, and/or alcohol consumption.

Because the study population was mostly homogeneous with respect to race/ethnicity and education, those with missing data on either of these variables (*n*=494) were retained with values assigned to a missing category. The final analytic sample was 4297 (778 women, 3519 men). Table 1 presents the distribution of demographic, health, and behavioral characteristics of the study population.

Commuting Distance and Health Outcomes

Commuting distance was negatively associated with weekly MET-minutes of moderate-to-vigorous physical activity and CRF and positively associated with BMI, waist circumference, and diastolic blood pressure in multivariate models without adjustment for CRF and physical activity (Model A; Table 2). Associations between commuting distance with BMI, waist circumference, and diastolic blood pressure remained significant, albeit attenuated for BMI and waist circumference, after adjustment for CRF and physical activity (Model B). Both systolic blood pressure and continuously measured metabolic syndrome became significant. Adjusted R^2 values generally increased after adding CRF and physical activity, particularly for the models with BMI and waist circumference as outcomes, suggesting that CRF and physical activity explain a considerable amount of variation in adiposity. No interactions were observed by gender, age, physical activity participation, or BMI.

When health outcomes were analyzed dichotomously, commuting distances of >15 miles were associated with lower odds of meeting moderate-to-vigorous physical activity recommendations and achieving high fitness levels and with higher odds of obesity and central adiposity (Model A; Table 3) with trends (p<0.01) observed for all of these outcomes except high fitness levels. Commuting distances of >10 miles were associated with lower odds of having elevated blood pressure (p-trend=0.006) but not with other metabolic risk outcomes, specifically elevated triglycerides, elevated blood glucose, reduced HDL cholesterol, and metabolic syndrome (data not shown). Significance was maintained only for associations with elevated blood pressure, after controlling for CRF and physical activity (Model B; Table 3).

Because self-reported history of high blood pressure does not accurately capture treatment for hypertension, one of the conditions specified in the international metabolic syndrome guidelines for high blood pressure,[33] self-reported history of high blood pressure was excluded from the definition of elevated blood pressure and added as a covariate. Because of this, associations between commuting distance and elevated blood pressure were attenuated, and significance remained only for commuting distance >20 miles (AOR=1.29, 95% CI=1.06, 1.58) suggesting that commuting distance is most strongly associated with the combined presence *and* history of high blood pressure. In additional sensitivity analyses, study findings were not appreciably different when assigning participants with missing covariate data (*n*=925) to missing categories. Associations were slightly attenuated (all by <20%) with the majority of differences in effect sizes being <5%.

Discussion

This study yielded new information about biological outcomes and commuting distance, an understudied and habitual source of sedentary behavior that is prevalent among employed adults and important for individuals with the additional exposure of occupational sitting. The findings suggest that commuting distance is adversely associated with moderate-to-vigorous physical activity, CRF, adiposity, and blood pressure but not blood lipids or fasting glucose.

This information provides important evidence about potential mediators in the relationship between time spent driving and cardiovascular mortality observed previously in this study population.[15]

A plausible mechanism between commuting distance and adiposity could be that longer commutes displace physical activity participation given (1) the independent associations with physical activity and CRF and (2) attenuation in associations with adiposity after adjustment by physical activity. At the same time, when examined as continuous variables, both BMI and waist circumference were associated with commuting distance even after adjustment for physical activity and CRF, suggesting an independent effect of commuting distance on adiposity likely via a reduction in overall energy expenditure.[39,40] Another factor that may contribute to the observed associations with adiposity may be that participants with long commutes were more likely to live in suburban neighborhoods, which often possess built environment features that are associated with physical inactivity and sedentary behavior.[41,42]

Associations of commuting distance with the other metabolic risk indicators were largely weak or nonsignificant, with the exception of blood pressure. This is plausible, given the strong influence of individual and environmental factors on these health indicators[43–46] and that commuting long distances via motorized travel represents only a portion of total sedentary time. Yet, associations with blood pressure were as strong in magnitude as those with physical activity and persisted even after adjustment for physical activity and adiposity.

Multiple mechanisms could be contributing to this relationship. First, automobile driving has been identified as a salient source of everyday stress, especially when drivers are faced with traffic congestion.[47–50] Because the Dallas–Fort Worth region is ranked among the top five most congested metropolitan areas in the U.S.,[51] those with longer commutes may be more likely to be exposed to heavy traffic resulting in higher stress levels and more time sitting. Daily commuting represents a source of chronic stress that has been positively correlated with physiologic consequences including high blood pressure, self-reported tension, fatigue, and other negative mental or physical health effects in some studies.[49, 52–55] Another explanation of the observed association between commuting distance and blood pressure, as well as adiposity, may be that commuting distance is related to unmeasured risk factors of hypertension, including worse diet, poor sleep, depression, anxiety, or social isolation.[56–58] These unmeasured variables may be related to long commutes as well as neighborhood factors associated with suburban communities that may limit opportunities for physical activity and social cohesion.[59–61]

This study has several strengths. Commuting distance was calculated based on street networks using a GIS instead of relying on self-report. In addition, the extensive physical examination provided a unique opportunity to assess CRF and measured BMI, as well as elements of the metabolic syndrome.

Limitations include the cross-sectional study design and limited generalizability of the study population, consisting of predominantly white, well-educated and healthier adults of middle-to-upper SES and under-representation of women. Although the homogeneity of the population with respect to education and race/ethnicity may improve internal validity, some residual confounding may be present due to other unmeasured socioeconomic variables (e.g., occupation and income). Other limitations include lack of information about the mode and frequency of commuting; however, it was anticipated that the vast majority of participants commuted by automobile given that more than 95% of the workers >16 years who worked outside the home commuted by private vehicle in 2005–2007 in the Dallas–Fort Worth–Arlington Metropolitan Statistical Area.[22]

In addition, information about time spent commuting and the validity of the network route to actual distance traveled by the participant were lacking. Differences in shortest versus actual route are expected for a variety of reasons (e.g., traffic, childcare). Categorizing commuting distance may have minimized some of this measurement error. Also, participants whose work addresses were their home addresses were excluded. Future studies are needed to examine how telecommuting and working from home affects health indicators.

Finally, commuting by automobile represents only one of many forms of sedentary behavior, and this study lacked data on other important contributors to sedentary time, such as occupational sitting and TV viewing. At the same time, time spent riding in a car has been shown to be a predictor of cardiovascular mortality in the population.[15] In addition, TV viewing is poorly correlated with total sedentary time in working populations,[62] and occupational sitting is expected to be common given that an estimated 90% or more of adults in this study population work in sedentary professional or managerial positions based on job title. Commuting distance represents a measured source of sedentary behavior with variability in this study population. Because we cannot rule out all competing explanations with these methodologic limitations, future prospective studies are needed in more-diverse populations with precise assessment of sedentary time across multiple behavioral domains to tease out the independent effects of passive commuting on health.[41]

Conclusion

This study contributed additional information about possible mechanisms underlying the increased risk of obesity, hypertension, and poor physical health observed among adults living in more-sprawling communities.[63–65] Multilevel strategies in the home, worksite, and community settings will be needed to mitigate the negative health consequences of long commutes faced by a substantial segment of the U.S. population.[41]

Acknowledgments

This study was supported in part by an American Cancer Society Mentored Research Scholar Grant (MRSG-07-016-01-CPPB), CDC, Prevention Research Centers Program (Cooperative Agreement U48DP001903), NIH grants (AG06945 and HL62508), and the Communities Foundation of Texas on recommendation of Nancy Ann and Ray L. Hunt. We thank Dr. Kenneth H. Cooper for establishing the Cooper Center Longitudinal Study, the Cooper Clinic physicians, nurses, and technicians who collected the clinical data, and the data management team at The Cooper Institute. We also thank Drs. William Haskell and Ross Brownson for their constructive input on the design and analysis and Katelin Bugler for preparing the address data.

References

1. Physical Activity Guidelines Advisory Committee. Physical Activity Guidelines Advisory Committee Report, 2008. Washington, DC: DHHS; 2008.
2. WHO. Global Strategy on Diet, Physical Activity and Health. Geneva, Switzerland: WHO; 2004.
3. Brownson RC, Boehmer TK, Luke DA. Declining rates of physical activity in the U.S.: What are the contributors? Annu Rev Public Health. 2005; 26:421–43. [PubMed: 15760296]
4. Hamilton MT, Hamilton DG, Zderic TW. Role of low energy expenditure and sitting in obesity, metabolic syndrome, type 2 diabetes, and cardiovascular disease. Diabetes. 2007; 56:2655–67. [PubMed: 17827399]
5. Owen N, Healy GN, Matthews CE, Dunstan DW. Too much sitting: the population health science of sedentary behavior. Exerc Sport Sci Rev. 2010; 38:105–13. [PubMed: 20577058]
6. Thorp AA, Owen N, Neuhaus M, Dunstan DW. Sedentary behaviors and subsequent health outcomes in adults a systematic review of longitudinal studies, 1996–2011. Am J Prev Med. 2011; 41:207–15. [PubMed: 21767729]

7. Bey L, Hamilton MT. Suppression of skeletal muscle lipoprotein lipase activity during physical inactivity: a molecular reason to maintain daily low-intensity activity. J Physiol. 2003; 551:673–82. [PubMed: 12815182]
8. Hamilton MT, Hamilton DG, Zderic TW. Exercise physiology versus inactivity physiology: an essential concept for understanding lipoprotein lipase regulation. Exerc Sport Sci Rev. 2004; 32:161–6. [PubMed: 15604935]
9. Katzmarzyk PT, Church TS, Craig CL, Bouchard C. Sitting time and mortality from all causes, cardiovascular disease, and cancer. Med Sci Sports Exerc. 2009; 41:998–1005. [PubMed: 19346988]
10. Lindstrom M. Means of transportation to work and overweight and obesity: a population-based study in southern Sweden. Prev Med. 2008; 46:22–8. [PubMed: 17706273]
11. Lopez-Zetina J, Lee H, Friis R. The link between obesity and the built environment. Evidence from an ecological analysis of obesity and vehicle miles of travel in California. Health Place. 2006; 12:656–64. [PubMed: 16253540]
12. Pendola R, Gen S. BMI, auto use, and the urban environment in San Francisco. Health Place. 2007; 13:551–6. [PubMed: 16621666]
13. Wen LM, Orr N, Millett C, Rissel C. Driving to work and overweight and obesity: findings from the 2003 New South Wales Health Survey, Australia. Int J Obes (Lond). 2006; 30:782–6. [PubMed: 16404406]
14. Frank LD, Andresen MA, Schmid TL. Obesity relationships with community design, physical activity, and time spent in cars. Am J Prev Med. 2004; 27:87–96. [PubMed: 15261894]
15. Warren TY, Barry V, Hooker SP, Sui X, Church TS, Blair SN. Sedentary behaviors increase risk of cardiovascular disease mortality in men. Med Sci Sports Exerc. 2010; 42:879–85. [PubMed: 19996993]
16. Tudor-Locke C, Johnson WD, Katzmarzyk PT. Frequently reported activities by intensity for U.S. adults: the American Time Use Survey. Am J Prev Med. 2010; 39:e13–20. [PubMed: 20837277]
17. Hu, PS.; Reuscher, TR. Summary of travel trends: 2001 National Household Travel Survey. Washington, D.C: U.S. Department of Transportation, Federal Highway Administration; 2004.
18. Davison KK, Werder JL, Lawson CT. Children's active commuting to school: current knowledge and future directions. Preventing chronic disease. 2008; 5:A100. [PubMed: 18558018]
19. Hamer M, Chida Y. Active commuting and cardiovascular risk: a meta-analytic review. Prev Med. 2008; 46:9–13. [PubMed: 17475317]
20. Pisarski, AE. Commuting in America III: the Third National Report on Commuting Patterns and Trends. Washington, D.C: Transportation Research Board of the National Academies; 2006. Report No.: NCHRP Report 550 and TCRP Report 110
21. McGuckin, NA.; Srinivasan, N. Journey to work in the US and its major metropolitan areas - 1960–2000. Washington, D.C: U.S. Department of Transportation Federal Highway Administration; 2003. Report No.: FHWA-EP-03-058
22. American Community Survey, 2005–2007. U.S. Census Bureau; factfinder.census.gov
23. Kohl HW, Blair SN, Paffenbarger RS Jr, Macera CA, Kronenfeld JJ. A mail survey of physical activity habits as related to measured physical fitness. Am J Epidemiol. 1988; 127:1228–39. [PubMed: 3369421]
24. Oliveria SA, Kohl HW 3rd, Trichopoulos D, Blair SN. The association between cardiorespiratory fitness and prostate cancer. Med Sci Sports Exerc. 1996; 28:97–104. [PubMed: 8775361]
25. Ainsworth BE, Haskell WL, Whitt MC, et al. Compendium of physical activities: an update of activity codes and MET intensities. Med Sci Sports Exerc. 2000; 32:S498–504. [PubMed: 10993420]
26. Balke B, Ware RW. An experimental study of physical fitness of Air Force personnel. U. S Armed Forces. Med J. 1959; 10:675–88.
27. Wei M, Kampert JB, Barlow CE, et al. Relationship between low cardiorespiratory fitness and mortality in normal-weight, overweight, and obese men. JAMA. 1999; 282:1547–53. [PubMed: 10546694]
28. Lee CD, Blair SN, Jackson AS. Cardiorespiratory fitness, body composition, and all-cause and cardiovascular disease mortality in men. Am J Clin Nutr. 1999; 69:373–80. [PubMed: 10075319]

29. Blair SN, Kohl HW 3rd, Barlow CE, Paffenbarger RS Jr, Gibbons LW, Macera CA. Changes in physical fitness and all-cause mortality. A prospective study of healthy and unhealthy men. JAMA. 1995; 273:1093–8. [PubMed: 7707596]
30. ACSM. Guidelines for Exercise Testing and Prescription. 7. Philadelphia, PA: Lippincott Williams & Wilkins; 2005.
31. Pollock ML, Foster C, Schmidt D, Hellman C, Linnerud AC, Ward A. Comparative analysis of physiologic responses to three different maximal graded exercise test protocols in healthy women. Am Heart J. 1982; 103:363–73. [PubMed: 7064770]
32. Pollock ML, Bohannan RL, Cooper KH, et al. A comparative analysis of four protocols for maximal treadmill stress testing. Am Heart J. 1976; 92:39–46. [PubMed: 961576]
33. Alberti KG, Eckel RH, Grundy SM, et al. Harmonizing the metabolic syndrome: a joint interim statement of the International Diabetes Federation Task Force on Epidemiology and Prevention; National Heart, Lung, and Blood Institute; American Heart Association; World Heart Federation; International Atherosclerosis Society; and International Association for the Study of Obesity. Circulation. 2009; 120:1640–5. [PubMed: 19805654]
34. Wijndaele K, Beunen G, Duvigneaud N, et al. A continuous metabolic syndrome risk score: utility for epidemiological analyses. Diabetes Care. 2006; 29:2329. [PubMed: 17003322]
35. Wijndaele K, Duvigneaud N, Matton L, et al. Sedentary behaviour, physical activity and a continuous metabolic syndrome risk score in adults. Eur J Clin Nutr. 2009; 63:421–9. [PubMed: 17971826]
36. Wijndaele K, Duvigneaud N, Matton L, et al. Muscular strength, aerobic fitness, and metabolic syndrome risk in Flemish adults. Med Sci Sports Exerc. 2007; 39:233–40. [PubMed: 17277586]
37. Mukamal KJ, Chen CM, Rao SR, Breslow RA. Alcohol consumption and cardiovascular mortality among U.S. adults, 1987 to 2002. J Am Coll Cardiol. 2010; 55:1328–35. [PubMed: 20338493]
38. Mantel N. Chi-square tests with one degree of freedom; extensions of the Mantel-Haenszel procedure. J Am Stat Assoc. 1963; 58:690–700.
39. Levine JA, Eberhardt NL, Jensen MD. Role of nonexercise activity thermogenesis in resistance to fat gain in humans. Science. 1999; 283:212–4. [PubMed: 9880251]
40. Levine JA, Lanningham-Foster LM, McCrady SK, et al. Interindividual variation in posture allocation: possible role in human obesity. Science. 2005; 307:584–6. [PubMed: 15681386]
41. Owen N, Sugiyama T, Eakin EE, Gardiner PA, Tremblay MS, Sallis JF. Adults' sedentary behavior determinants and interventions. Am J Prev Med. 2011; 41:189–96. [PubMed: 21767727]
42. Sallis JF, Glanz K. Physical activity and food environments: solutions to the obesity epidemic. Milbank Q. 2009; 87:123–54. [PubMed: 19298418]
43. Ervin RB. Prevalence of metabolic syndrome among adults 20 years of age and over, by sex, age, race and ethnicity, and body mass index, U.S. 2003–2006. National Health Statistics Report. 2009; 13:1–7.
44. Li F, Harmer P, Cardinal BJ, et al. Built environment and 1-year change in weight and waist circumference in middle-aged and older adults: Portland Neighborhood Environment and Health Study. Am J Epidemiol. 2009; 169:401–8. [PubMed: 19153214]
45. Li F, Harmer P, Cardinal BJ, Vongjaturapat N. Built environment and changes in blood pressure in middle aged and older adults. Prev Med. 2009; 48:237–41. [PubMed: 19297686]
46. Sinclair A, Viljoen A. The metabolic syndrome in older persons. Clin Geriatr Med. 2010; 26:261–74. [PubMed: 20497845]
47. Evans GW, Wener RE, Phillips D. The morning rush hour : predictability and commuter stress. Environment and Behavior. 2002; 34:521–30.
48. Hennessy DA, Wiesenthal DL, Kohn PM. The influence of traffic congestion, daily hassles, and trait stress susceptibility on state driver stress: an interactive perspective. J Applied Biobehavioral Res. 2000; 5:162–79.
49. Kluger AN. Commute variability and strain. J Organ Behav. 1998; 19:147–65.
50. Koslowsky M. Commuting stress: problems of definition and variable identification. Applied Psychology: An International Review. 1997; 46:153–73.
51. INRIX. INRIX National Traffic Scorecard 2008 Annual Report. 2009.

52. Costa G, Pickup L, Di Martino V. Commuting--a further stress factor for working people: evidence from the European Community. II. An empirical study. Int Arch Occup Environ Health. 1988; 60:377–85. [PubMed: 2968322]
53. Kageyama T, Nishikido N, Kobayashi T, Kurokawa Y, Kaneko T, Kabuto M. Long commuting time, extensive overtime, and sympathodominant state assessed in terms of short-term heart rate variability among male white-collar workers in the Tokyo megalopolis. Ind Health. 1998; 36:209–17. [PubMed: 9701898]
54. Walsleben JA, Norman RG, Novak RD, O'Malley EB, Rapoport DM, Strohl KP. Sleep habits of Long Island Rail Road commuters. Sleep. 1999; 22:728–34. [PubMed: 10505818]
55. Sparrenberger F, Cichelero FT, Ascoli AM, et al. Does psychosocial stress cause hypertension? A systematic review of observational studies. J Hum Hypertens. 2009; 23:12–9. [PubMed: 18615099]
56. Yusuf S, Hawken S, Ounpuu S, et al. Effect of potentially modifiable risk factors associated with myocardial infarction in 52 countries (the INTERHEART study): case-control study. Lancet. 2004; 364:937–52. [PubMed: 15364185]
57. Chobanian AV, Bakris GL, Black HR, et al. The Seventh Report of the Joint National Committee on Prevention, Detection, Evaluation, and Treatment of High Blood Pressure: the JNC 7 report. JAMA. 2003; 289:2560–72. [PubMed: 12748199]
58. Nagai M, Hoshide S, Kario K. Sleep duration as a risk factor for cardiovascular disease- a review of the recent literature. Curr Cardiol Rev. 2010; 6:54–61. [PubMed: 21286279]
59. Besser LM, Marcus M, Frumkin H. Commute time and social capital in the U. S Am J Prev Med. 2008; 34:207–11.
60. Putnam, RD. Bowling alone: the collapse and revival of American community. New York: Touchstone; 2000.
61. Handy, SL. Critical assessment of the literature on the relationships among transportation, land use, and physical activity. Davis, CA: Department of Environmental Science and Policy, University of California, Davis; 2004 Jul. Report No.: Prepared for the Committee on Physical Activity, Health, Transportation, and Land Use
62. Clark BK, Healy GN, Winkler EA, et al. Relationship of television time with accelerometer-derived sedentary time: NHANES. Med Sci Sports Exerc. 2011; 43:822–8. [PubMed: 20980928]
63. Ewing R, Schmid T, Killingsworth R, Zlot A, Raudenbush S. Relationship between urban sprawl and physical activity, obesity, and morbidity. Am J Health Promot. 2003; 18:47–57. [PubMed: 13677962]
64. Lopez R. Urban sprawl and risk for being overweight or obese. Am J Public Health. 2004; 94:1574–9. [PubMed: 15333317]
65. Sturm R, Cohen DA. Suburban sprawl and physical and mental health. Public Health. 2004; 118:488–96. [PubMed: 15351221]

NIH-PA Author Manuscript
NIH-PA Author Manuscript

Table 1

Characteristics of the study population, Cooper Center Longitudinal Study, 2000–2007

Characteristic	M (SD) or %
N	4297
Sociodemographics	
Age	47.1 (8.7)
Male gender	81.9
Ethnicity	
White	92.2
Other	5.3
Missing	2.6
Years of education	
Less than college	12.5
College graduate or higher	77.8
Missing	9.7
Marital status	
Single	6.3
Married	87.0
Divorced/widowed	6.7
Children in home	57.9
Health behaviors and history	
Smoking	
Never	56.8
Former	30.5
Current	12.8
Alcohol consumption	
None	16.4
Light	28.9
Moderate	43.7
Heavy	11.1
Personal history of high cholesterol	28.9
Personal history of high blood pressure	14.8
Family history of diabetes	21.4
Exposure Measure	
Commuting distance	12.1 (9.1)
Commuting distance, miles	
1–5 miles	24.4
6–10 miles	27.2
11–15 miles	16.8
16–20 miles	13.1
>20 miles	18.5
Outcome Measures	

Characteristic	M (SD) or %
Weekly MET-min of moderate-to-vigorous physical activity	1346.3 (1287.5)
Cardiorespiratory fitness (max MET level)	11.2 (2.2)
BMI	26.9 (4.3)
Waist circumference (cm)	90.9 (13.0)
Triglycerides (log, mg/dl)	4.6 (0.5)
HDL cholesterol (mg/dl)	52.3 (14.1)
Fasting plasma glucose (mg/dl)	95.7 (11.5)
Systolic blood pressure (mmHg)	121.4 (13.0)
Diastolic blood pressure (mmHg)	82.1 (9.4)

HDL, high-density lipoprotein

NIH-PA Author Manuscript
NIH-PA Author Manuscript

Table 2

Unstandardized regression coefficients for associations with commuting distance, Cooper Center Longitudinal Study, 2000–2007

Dependent Variable	Model A[a]			Model B[b]		
	β (95% CI)	*p*-value	Adjusted R^{2c}	*β* (95% CI)	*p*-value	Adjusted R^{2c}
Weekly MET-min moderate-to-vigorous physical activity [d]	**−9.464 (−13.656,−5.272)**	**<0.00**	0.032	--		
Cardiorespiratory fitness [d]	**−0.008 (−0.014, −0.003)**	**0.003**	0.459	--		
BMI	**0.032 (0.019,0.046)**	**<0.001**	0.112	**0.017 (0.005,0.028)**	**0.004**	0.354
Waist circumference (cm) [e]	**0.077 (0.039,0.117)**	**0.001**	0.355	**0.032 (0.000,0.065)**	**0.049**	0.571
Triglycerides (log, mg/dl) [d, f]	−0.001 (−0.002,0.001)	0.439	0.184	−0.001 (−0.003,0.000)	0.131	0.218
HDL cholesterol (mg/dl) [d, f]	−0.016 (−0.056,0.023)	0.415	0.360	−0.004 (−0.042,0.035)	0.857	0.380
Fasting plasma glucose (mg/dl) [d]	−0.004 (−0.041,0.034)	0.846	0.149	−0.006 (−0.044,0.031)	0.748	0.151
Systolic blood pressure(mmHg) [d, g]	0.036 (−0.002,0.074)	0.064	0.224	**0.038 (0.001,0.076)**	**0.047**	0.223
Diastolic blood pressure(mmHg) [d, g]	**0.044 (0.016,0.073)**	**0.002**	0.174	**0.044 (0.015,0.072)**	**0.003**	0.174
Continuous metabolic syndrome[e]	0.004 (−0.001,0.009)	0.118	0.130	**0.005 (0.000,0.010)**	**0.049**	0.135

HDL, high-density lipoprotein; CRF, cardiorespiratory fitness

[a] Model A: Adjusted for age, gender, education, race, marital status, children in home, smoking status, alcohol intake, family history of diabetes

[b] Model B: Adjusted for all covariates in Model A plus CRF and weekly MET-min of moderate-to-vigorous physical activity

[c] Adjusted R^2 gives an estimate of explained variance, taking into account the sample size.

[d] Additional adjustment for BMI

[e] Sample size reduced to 3306 due to missing values for waist circumference

[f] Additional adjustment for history of high cholesterol

[g] Additional adjustment for history of high blood pressure

Table 3

Prevalence (%) and adjusted ORs (95% CIs) for associations with commuting distance, Cooper Center Longitudinal Study, 2000–2007

Dependent Variable	Miles					*p*- trend
	0–5	**6–10**	**11–15**	**16–20**	**>20**	
n	1047	1170	721	564	795	
Meets physical activity recommendations	75.7	73.6	1.3	69.2	66.5	
Model A [a, c]	1.0 (Ref)	0.88 (0.73, 1.07)	0.82 (0.66, 1.02)	**0.77 (0.61, 0.97)**	**0.66 (0.54, 0.82)**	0.002 --
High fitness	27.7	27.4	21.6	18.6	21.5	
Model A [a, c]	1.0 (Ref)	0.95 (0.78, 1.17)	0.79 (0.62, 1.00)	**0.67 (0.51, 0.88)**	0.82 (0.64, 1.03)	0.093 --
Obese	18.2	16.5	21.1	25.2	22.4	
Model A [a]	1.0 (Ref)	0.91 (0.73, 1.14)	1.19 (0.93,1.52)	**1.52 (1.18,1.95)**	**1.26 (1.00, 1.60)**	0.003
Model B [b]	1.0 (Ref)	0.88 (0.68,1.13)	1.06 (0.81, 1.39)	1.30 (0.98, 1.73)	1.10 (0.84, 1.44)	0.037
Central adiposity [c]	18.0	15.9	21.0	24.1	24.1	
Model A [a]	1.0 (Ref)	0.90 (0.69,1.16)	1.25 (0.95,1.66)	**1.49 (1.12,2.00)**	**1.45 (1.11,1.89)**	0.002
Model B [b,d]	1.0 (Ref)	0.88 (0.66,1.18)	1.20 (0.88,1.64)	1.30 (0.93,1.82)	1.32 (0.97,1.80)	0.070
Elevated blood pressure	44.9	45.0	49.0	52.0	52.2	
Model A [a, c]	1.0 (Ref)	1.11 (0.92,1.34)	**1.23 (1.00,1.52)**	**1.34 (1.07,1.67)**	**1.35 (1.10,1.65)**	0.006
Model B [b]	1.0 (Ref)	1.11 (0.93,1.34)	**1.24 (1.07,1.68)**	**1.34 (1.07,1.68)**	**1.36 (1.11,1.66)**	0.157

Note: Meets physical activity recommendations= ≥500 MET-minutes of moderate-to-vigorous activity per week; high fitness= ≥20th percentile age–gender standardized CRF distribution; obese=BMI >30; central adiposity=waist circumference ≥102 cm for men and ≥88 cm for women; elevated blood pressure=systolic ≥130 mmHg or diastolic ≥85 mmHg, or history of high blood pressure

[a] Model A: adjusted for age, gender, education, race, marital status, children in home, smoking status, alcohol intake, family history of diabetes

[b] Model B: adjusted for all covariates in Model A plus CRF and weekly MET-min of moderate-to-vigorous physical activity

[c] Additional adjustment for BMI

[d] Sample size reduced to 3306 due to missing values for waist circumference

CRF, cardiorespiratory fitness; HDL, high-density lipoprotein