Published in final edited form as:

Soc Sci Med. 2011 December ; 73(12): 1707–1716. doi:10.1016/j.socscimed.2011.09.032.

Association between Neighborhood Walkability, Cardiorespiratory Fitness and Body-Mass Index

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Abstract

Many studies have found cross-sectional associations between characteristics of the neighborhood built environment and physical activity (PA) behavior. However, most are based on self-reported PA, which is known to result in overestimation of PA and differential misclassification by demographic and biological characteristics. Cardiorespiratory fitness (CRF) is an objective marker of PA because it is primarily determined by PA. Furthermore, it is causally related to long-term health outcomes. Therefore, analyses of the association between CRF and built environment could strengthen arguments for the importance of built environment influences on health. We examined the association between neighborhood walkability and CRF and body-mass index (BMI). This cross-sectional analysis included 16,543 adults (5,017 women, 11,526 men) aged 18–90 years with home addresses in Texas who had a comprehensive clinical examination between 1987 and 2005. Outcomes included CRF from total duration on a maximal exercise treadmill test and measured BMI. Three neighborhood walkability factors emerged from principal components analyses of block-group measures derived from the U.S. Census. In multilevel adjusted analyses, the neighborhood walkability factors were significantly associated with CRF and BMI among men and women in the expected direction. An interaction between one of the neighborhood factors and age was also observed. The interaction suggested that living in neighborhoods with older homes and with residents traveling shorter distances to work was more strongly positively associated with CRF among younger adults and more strongly negatively associated with BMI among older adults. In conclusion, neighborhood characteristics hypothesized to support more PA and less driving were associated with higher levels of CRF and lower BMI. Demonstration of an association between built environment characteristics and CRF is a significant advance over past studies based on self-reported PA. Nevertheless, stronger causal evidence depends on more robust study designs and sophisticated measures of the environment, behavior, and their physiological consequences.

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Keywords

physical activity; exercise; walking; cardiorespiratory fitness; obesity; neighborhood; built environment; USA

Introduction

Despite strong evidence that physical activity (PA) and healthy weight lower risk of morbidity and mortality from various chronic diseases and conditions (Physical Activity Guidelines Advisory Committee, 2008), approximately two-thirds of U.S. adults were overweight or obese in 2007–2008 (Flegal et al., 2010), and one-third reported not meeting the minimum levels of PA to achieve health benefits in 2007 (Centers for Disease Control and Prevention, 2008), with adherence rates significantly lower when using objectively measured PA from accelerometers (Troiano et al., 2008).

Influences on PA include individual, interpersonal, social and physical environmental and policy factors, as described in ecological models of health behavior (McLeroy et al., 1988; Sallis et al., 2008). Strategies that change policies and environments to support PA are recognized as a critical component to health promotion in the U.S. and internationally (U.S. National Physical Activity Plan, 2010; World Health Organization, 2009). There are many alternative and complementary explanations for geospatial and temporal variation in PA in addition to the ecological model. Examples include theories emphasizing time constraints (Copperman et al., 2007), attachment to place (Low et al., 1992), and economic factors (Zimmerman, 2009). This study focused on the ecological model because it offers an overarching explanatory framework that encompasses the built environment and because the data set analyzed did not include constructs from some of these more specific alternatives.

Mounting evidence from diverse disciplines such as public health and urban planning demonstrates weak to moderate associations of walking and cycling for transportation, total PA and obesity with contextual features of the built environment, such as residential density, land-use mix, street connectivity and proximity to public transportation (Feng et al., 2009; Heath et al., 2006; Humpel et al., 2002; Saelens et al., 2008). Although most of this research has been conducted in the U.S., Australia, and Canada, many studies from other countries, including from low- and middle-income countries, report significant associations between the built environment and PA (Cervero et al., 2009; Sallis et al., 2009a) and obesity (Stafford et al., 2007; Van Dyck et al., 2010).

To date, most built environment studies have assessed PA behaviors by self-report methods (Humpel et al., 2002; Saelens et al., 2008). Measures of self-reported PA behavior often suffer from low reliability and validity compared with objective PA measures, such as those derived from accelerometry (Prince et al., 2008). Yet, population-based studies of the built environment among adults that have used accelerometers to measure total PA have found mixed results (Frank et al., 2005; Oakes et al., 2007; Sallis et al., 2009b). More research is needed with objective assessment of PA, as well as body-mass index (BMI) (Papas et al., 2007), to clarify whether favorable built environments have the potential to increase overall activity levels and curb the obesity epidemic.

The primary outcome for our study was cardiorespiratory fitness (CRF), a highly sensitive and objective measure of changes in response to PA (Physical Activity Guidelines Advisory Committee, 2008) and recent PA (Paffenbarger et al., 1993). It is also a marker for functional capacity and ability to perform activities of daily living, especially in older individuals. CRF is defined as the ability of the circulatory and respiratory systems to supply

oxygen during sustained PA (Physical Activity Guidelines Advisory Committee, 2008). CRF and PA are highly associated with each other, with increases in activity resulting in increases in fitness (Blair et al., 1995; Paffenbarger et al., 1993). Numerous studies have shown that moderate-intensity activities, including walking, predict higher fitness (Murphy et al., 2007) and lower risk of heart disease and mortality (Blair et al., 1995; Zheng et al., 2009). CRF is a strong independent predictor of overall mortality and of morbidity and mortality due to various chronic diseases (U. S. Department of Health and Human Services, 1996).

This study extended previous research on the built environment by examining associations between neighborhood walkability and objective measurements of the benefits of PA, namely CRF and measured BMI. We hypothesized that this association would operate via PA behavior, such that adults living in more walkable neighborhoods as characterized by the physical environment (e.g., connected streets, higher density) and by social norms with respect to automobile orientation (e.g., lower share of commutes by automobile) would engage in more PA—most likely walking, jogging, and bicycling. Higher volumes of PA are associated with increased CRF and lower BMI. Moreover, this study examined understudied interactions with age.

Because study participants were geographically dispersed across Texas, readily available Census variables were used to characterize dimensions of the built environment, namely variables related to *housing and population density*, the most widely used built environment measure because of its ease of measurement and policy relevance supporting mixed-use development and discouraging strictly automobile-oriented design (Handy et al., 2002); *median home age*, a proxy measure for urban design and street connectivity since older neighborhoods are more likely to be pedestrian-oriented with sidewalks, denser interconnected street networks, and mixed land uses (Berrigan et al., 2002; Handy, 1996a, b; Smith et al., 2008); average *commute times to work* to represent land-use mix and level of urbanization; and *modes of commuting to work* to reflect whether the built environment makes walking and bicycling or use of public transportation feasible and attractive (Craig et al., 2002), in addition to reflecting social norms about automobile orientation. Overall, we hypothesized that individuals living in neighborhoods with greater population and housing density, older homes, shorter commutes, and higher shares of commuting by public transportation, walking, and bicycling would have higher levels of CRF and lower mean BMI.

Methods

Study Design and Population

This multilevel study used data from the Aerobics Center Longitudinal Study (ACLS). The subjects included in the ACLS were patients seen at the Cooper Clinic in Dallas, Texas. These patients came to the clinic for preventive medical examinations and for counseling regarding diet, exercise, and other lifestyle factors associated with chronic disease risk. Participants were volunteers, not paid, and not recruited to the study as for a clinical trial. Most were self-referred, although a substantial (but unknown) number were referred by their employers for the examination. Participants signed an informed consent for the clinical examinations. The institutional review boards of the Cooper Institute and Washington University approved the current study.

This study included adults aged 18–90 years with <45 reported sick days in the past year, with home addresses in Texas, with non-missing data on the exposure, outcome, and covariate measures of interest, and with an examination between 1987 and 2005. For

patients with multiple examinations during this time period, only the most recent examination was included.

Data Collection

Clinical examination—Each patient completed a detailed medical history questionnaire consisting of demographic, health habits, and health history information. In addition, each patient underwent an evaluation that included a maximal exercise treadmill test, body composition assessment, blood chemistry analysis, blood pressure measurement, and a physical examination by a physician.

Geocoding addresses—Patient addresses were successfully geocoded by Mapping Analytics Inc. (Rochester, NY). Of 17,973 participants with complete data on outcome measures, 96.7% (n=17,373) had addresses that were assigned to a latitude/longitude corresponding to the location of the home address. Addresses with low positional accuracy (n=600 geocoded to zip code centroid or post office box) were excluded. A map illustrating the geographic distribution of residents across the state of Texas is provided in Figure 1.

Measures

Cardiorespiratory fitness and body mass index—CRF was determined by a maximal exercise treadmill test using a modified Balke protocol (Balke et al., 1959) as previously described (Blair et al., 1995; Wei et al., 1999). Patients were encouraged to give a maximal effort, and the test end point was volitional exhaustion or termination by the physician for medical reasons. Treadmill time was converted to maximal metabolic equivalents (MET) values as a standard measure of CRF (Pollock et al., 1976; Pollock et al., 1982). Time on treadmill with this protocol is highly correlated with VO_{2max} ($r=0.94$ in women (Pollock et al., 1982) and $r=0.92$ in men (Pollock et al., 1976)). Treadmill time expressed in METs is analogous to maximal aerobic power (peak VO_2) and is an objective laboratory measure of CRF. Measured BMI was defined as weight in kilograms divided by height in meters squared.

Neighborhood variables—Census data at the block-group level were used to define the participants' neighborhood environments; hereafter, "block group" and "neighborhood" will be used interchangeably. Representing the lowest-level geographic entity for which the Census Bureau tabulates sample data, the block group was chosen as the best approximation of the neighborhood in the vicinity of participants' homes.

Measures for neighborhood walkability were obtained for the block group of residence from the U.S. Census from 1990 (for participants with examinations in 1987–1995) and 2000 (for participants with examinations in 1996–2005). Block-group level measures of population density, housing type, median home age, and commuting patterns represented neighborhood walkability as described previously.

Block-group variables of interest are presented in Table 1. Principal components analysis (PCA) was used to reduce the number of Census block-group variables used to characterize the neighborhoods where participants resided. Using orthogonal varimax rotation, three factors with eigenvalue >1 were extracted, accounting for 70.5% of the total variance. Each of the factor scores were reverse coded so that higher scores corresponded to environments hypothesized to be more conducive to walking. Reverse-coded factor 1 was named "high density" with higher values corresponding to block groups with higher population and housing unit density. Reverse-coded factor 2 was named "traditional core" with higher values corresponding to block groups with older homes and residents with shorter commute times. Reverse-coded factor 3 was named "non-auto commuting" with higher values

corresponding to block-groups with a higher proportion of commute trips made by walking, bicycling, or public transportation. A map of block groups by the *traditional core* factor is illustrated in Figure 2.

Covariates—Block group-level race/ethnicity (percent non-Hispanic Black and percent Hispanic), and poverty (percent below 200% of the poverty level) were included as covariates, as well as individual age, gender, and year of examination. We also controlled for years of education (7–12, 13–16, >16), and race (White or other) among the 4,418 men and 2,546 women with non-missing data on these variables to assess how effect estimates changed with and without adjustment for these covariates.

In addition, because physical activity mediates between the built environment and CRF and BMI, we controlled for PA in some models. We used self-reported participation in outdoor PA in the past three months, including any participation in walking, jogging/running, or bicycling – activities more likely to be associated with the neighborhood built environment. In sensitivity analyses, we assessed how effect size and statistical significance changed after controlling for weekly minutes of outdoor PA weighted by each activity's assigned metabolic equivalents (Ainsworth et al., 2000) instead of participation. Using this more precise variable for levels of outdoor PA reduced the sample size by 35% due to missing data on the frequency and/or duration of activity types.

Analysis

Study population characteristics were compared by gender using the t-test for continuous variables and the chi-square test for categorical variables. Mixed-effect models allowed for the simultaneous estimation of the effects of neighborhood-level and individual-level factors, while accounting for non-independence of observations within neighborhoods (Singer, 1998). All models included a random intercept for each neighborhood to allow estimation of (1) percentage of total variance in the outcome explained by between-neighborhood variance, and (2) percentage of between-neighborhood variance in outcome explained by individual- and neighborhood-level variables (Singer, 1998).

A series of models were fit to the data for each of the outcomes, CRF and BMI. First, we fit the random intercept-only model to describe the heterogeneous mean outcome among the neighborhoods in the study population (Model 0). Then, we entered the neighborhood factors of interest (Model 1), followed by the other neighborhood covariates (percent non-Hispanic black, percent Hispanic, percent below 200% poverty), and individual age, examination year, and BMI (for the model with CRF as the outcome; Model 2). Next, we entered the outdoor PA variable (for the CRF and BMI models; Model 3) and CRF (for the BMI model only; Model 4) to evaluate how effect sizes and statistical significance of the walkability factors changed when controlling for these potential mediators. Any observed attenuation in the association between neighborhood walkability and CRF would lend support to the hypothesis that PA mediates BE and CRF. Finally, we tested statistical interaction between each of the walkability factors and individual-level age (Model 5). For each step, we tested the statistical significance of those variables of interest using the approximate t-test for single parameters and approximate F-test for several related parameters. We also compared the change in between-neighborhood variation to determine the effect of residence after adjusting for other variables in the model. All continuous covariates were grand-centered at the mean value. Analyses were conducted using the SAS Software for Windows version 9.2 (SAS Institute Inc.).

Results

Characteristics of the Study Population

The study population included 16,543 participants aged 18–90 years with geocoded addresses and complete data on all exposure and outcome variables and covariates (Table 2). The majority of participants were male. No meaningful differences in age were observed between men and women. Women were more likely to be White and have lower levels of education; however, the data on these variables were missing for a significant proportion of the population. Among participants with examinations in 1996 or later (when race was added to the medical history questionnaire), 94% were White. Women were more likely to report participating in outdoor PA than men. The mean MET level, mean BMI, and proportion of adults who were overweight or obese were higher among men than women. Given these differences, all statistical models were stratified by gender.

Characteristics of the Neighborhoods

Three-fourths of the study population resided in the Dallas (58.2%) and Fort Worth-Arlington (16.8%), TX metropolitan statistical areas (Figure 1). The Austin and Houston metropolitan statistical areas had 6.9% and 3.4% of the population, respectively. Ninety-seven percent of participants lived in metropolitan counties.

The mean number of participants per block group was 5 (range 1–96). Compared to the characteristics of all block groups in Texas, block groups where study participants resided had a higher percentage of White residents, lower poverty levels, and higher income than all blocks groups in Texas (Table 3). Differences in housing stock, population density, and commuting patterns were also observed.

Associations between the Walkability Factors and CRF and BMI

Cardiorespiratory fitness—Based on the intraclass correlation coefficient (ICC), neighborhood of residence accounted for 8% and 7% of the variance in maximal METs among women and men, respectively. Most between-neighborhood variation in CRF was explained by individual- and neighborhood-level covariates. However, the modifiable neighborhood walkability characteristics accounted for 8% and 10% of neighborhood variation in CRF for women and men, respectively (Table 4). Among women and men, the *traditional core* factor was positively associated with CRF in both the unadjusted model (Model 1) and the adjusted models (Models 2 and 3). After controlling for individual-level age, examination year and BMI and neighborhood-level racial/ethnic composition and poverty, the *traditional core* factor was modestly but positively associated with CRF in women (Model 2). Further adjustment by outdoor PA attenuated the effects (Model 3). In all models the *non-auto commuting* factor was associated with CRF in men with slightly attenuated effects after adjustment for outdoor PA.

In addition, in the model without adjustment for outdoor PA, a small but significant interaction between the *traditional core* factor and age was observed among women ($p=0.048$) and men ($p<0.001$), whereby the positive effect of the *traditional core* factor on CRF decreased among women and men with increasing age (Figure 3). The interaction remained significant in men ($p<0.001$) but not women ($p=0.053$) after adjustment for outdoor PA. The interaction suggests that living in older neighborhoods with shorter commutes by residents had a stronger effect on CRF among younger adults. This association was negligible in magnitude among older adults.

In sensitivity analyses, the effect sizes for the neighborhood factors remained virtually unchanged (β coefficients changed by $\leq|0.012|$ units) with and without adjustment for

weekly MET-minutes of outdoor PA among a subset of women and men with non-missing data on this variable (n=3,122 and 7,651, respectively). When restricting analyses to participants with non-missing data on education and race/ethnicity, we observed no differences in the main effect estimates with and without adjustment by education and race (β coefficients changed by $<|0.02|$ units).

Body-mass index—Only a small amount of the variance in BMI was explained by neighborhood of residence in the intercept-only model for women and men (ICC=0.05 and 0.04, respectively). The walkability factors explained 20% and 28% of the between-neighborhood variation in BMI among women and men, respectively (Model 1; Table 5). Considerably more of the between-neighborhood variation in BMI was explained by the covariates. Among women, the *traditional core* and *high density* factors were significantly inversely associated with BMI in adjusted models that excluded CRF and outdoor PA (Model 2). Adjustment for outdoor PA attenuated the effects (Model 3). Only the *traditional core* factor maintained statistical significance, albeit weaker in magnitude, in the fully adjusted model including CRF (Model 4). Among men, all three walkability factors were independently and inversely associated with BMI in all models.

We observed significant interactions between neighborhood walkability factors and age. Among women, interactions between the *traditional core* factor and age ($p=0.007$ in full model) were significant in both models (with and without adjustment for outdoor PA and CRF). Among men, the interaction with age became significant after adjustment for outdoor PA and CRF ($p<0.001$; Figure 4). Interactions with age suggested that the inverse effect of the *traditional core* factor on BMI increased among older adults. There appeared to be no meaningful association between the *traditional core* factor and BMI among younger adults. In sensitivity analyses, treatment of PA as a continuous variable and inclusion of education and race/ethnicity did not qualitatively alter the results (β coefficients changed by $<|0.05|$ units).

Discussion

This large multilevel study found that neighborhood characteristics hypothesized to support more PA and less driving were associated with higher levels of CRF and lower BMI. Demonstration of an association between built environment characteristics and CRF and BMI is a significant advance over past studies based solely on self-reported PA and obesity.

The direction and magnitude of associations observed in this study were consistent with other cross-sectional studies of the neighborhood built environment and physical activity or obesity (Ewing et al., 2003; Frank et al., 2004; Heath et al., 2006; Saelens et al., 2003; Smith et al., 2008). The current study found that, all else being equal, men and women in neighborhoods one standard deviation (SD=1.0) above the mean on the *traditional core* factor indicator would be expected to have BMIs 0.77 and 0.84 kg/m² lower, respectively, than those living in neighborhoods less than one standard deviation below the mean, using estimates from the model without adjustment for outdoor PA and CRF. This translates into approximately 5.3 fewer pounds of body weight for the gender-specific sample mean BMI and height. It is difficult to compare the effect sizes with other studies given differences in neighborhood measures, yet these effect sizes appear to fall within the range of those observed in other neighborhood walkability studies (e.g., (Rundle et al., 2007)) and higher than that observed in a U.S. study of the association between a county-level sprawl index and self-reported BMI (Ewing et al., 2003). The effects of walkability on CRF in the current study were modest; differences in CRF among residents living in neighborhoods above and below one standard deviation of the mean traditional core factor were 0.11 and 0.16 METs among men and women, respectively. A 1-MET increase in VO_{2max} has been associated

with a 12% and 17% greater survival for men (Myers et al., 2002) and women (Gulati et al., 2003), respectively. It is unknown at what magnitude a difference in VO_{2max} would achieve public health significance at a population level.

This study also found that younger participants were fitter and older participants had lower BMI if they lived in neighborhoods characterized by older homes and shorter average commute times. An explanation may be that, among younger adults, the neighborhood environment has a more direct impact on recent PA behaviors known to influence CRF. The lack of association between the *traditional core* factor and CRF among older adults may be attributed to the fact that CRF declines sharply with age regardless of activity level and is more likely determined by other factors such as comorbidities, genetic factors, and PA intensity (Fleg et al., 2005; Hawkins et al., 2003; Jackson et al., 2009). The stronger neighborhood effects on BMI with increasing age may be attributed to longer length of residence, and thus longer lifetime exposure to favorable and unfavorable built environments, when compared to younger adults. Unfortunately, we lacked information on duration of residence to test this hypothesis.

We hypothesized that more walkable neighborhoods support multiple forms of outdoor PA, which in turn improve CRF and healthy weight. Indeed, characteristics of the physical environment of neighborhoods have been associated with overall PA levels (McCormack et al., 2004) and overweight/obesity (Papas et al., 2007), and PA has been shown to mediate associations between neighborhood walkability and BMI (Van Dyck et al., 2010). CRF is sensitive to participation in both high-intensity activity (Swain et al., 2006; Wenger et al., 1986), and to increasing exercise volume (or total energy expenditure) at the same intensity (Church et al., 2007; Duscha et al., 2005). For example, in a large randomized trial in post-menopausal women, those who walked only 72 minutes/week had approximately a 5% improvement in CRF (Church et al., 2007). Therefore, the hypothesized mechanism for the observed association between neighborhood walkability and CRF, although modest in magnitude, is plausible, especially since adjustment by outdoor PA attenuated the association between the neighborhood walkability factors and CRF, as well as BMI.

An alternative (untested) explanation for these observations might be that discretionary time mediates the relationship between these neighborhood walkability factors and CRF and BMI. For people living further from work or errands, time spent driving may displace time that would otherwise be used for PA. Emerging travel behavior research shows a positive association between increased concentration of and accessibility to shops and services and amount of time spent on discretionary activities (Lee et al., 2009). How time use mediates the relationship between the built environment and energy expenditure requires further empirical examination. Another alternative explanation relates to self-selection, in that adults who like to exercise choose to live in activity-conducive neighborhoods. Self-selection could well be important because many study participants have the economic means to choose neighborhoods that conform to their preferences. Other studies have found that self-selection explains some, but not all, of the observed associations between neighborhood characteristics and PA (Frank et al., 2007), travel behavior (Cao et al., 2009) and BMI (Berry et al., 2010).

The major strengths of this study were the use of a large study population and examination of objective measures of CRF and BMI. Moreover, by using multilevel statistical methods, we were able to quantify and explain neighborhood variation in CRF and BMI, as well as assess the extent to which characteristics of the neighborhood were independently associated with individual-level CRF and BMI. The large sample size also permitted exploration of understudied interactions with age.

Several important limitations should be noted. First, although CRF represents an important objective marker of PA (Paffenbarger et al., 1993)) with strong links to multiple health outcomes, measures of CRF and the ability to improve fitness are affected by genetic composition, age, relative weight, and habits other than PA (Bouchard et al., 2001). The genetic contribution to CRF is in the range of 30–40% which is slightly less than other well-known factors, such as BMI and lipids (Bouchard, 1986). It is unlikely that the unmeasured predictors of CRF would be systematically correlated with neighborhood characteristics to bias the observed results. Second, the ACLS data suffers from extensive missing data on sociodemographic variables known to be associated with PA and obesity; however the effects of these unmeasured variables on the internal validity of the results are likely to be minimal given the homogeneity of the ACLS population with respect to socioeconomic position and given no observed differences in effect after adjustment by education and race. Third, the ACLS participants' health profiles and neighborhoods are not representative of the general population. Accumulating evidence suggests that walkability characteristics may be less relevant in influencing BMI among relatively disadvantaged groups as compared with more advantaged groups (Lovasi et al., 2009). If true, the current study may have been more likely to detect an association. Yet, others have observed no difference in effects by neighborhood SES (Sallis et al., 2009b). Replication in diverse samples would add to the generalizability of these results. Fourth, the metropolitan areas in Texas do not represent all U.S. cities. Nevertheless, they share many features with sprawling metropolitan areas worldwide (Ewing et al., 2003). Also, limited variability in characteristics of urban form in Texas cities, particularly in neighborhoods where these participants lived, could attenuate the association between neighborhood characteristics, CRF, and BMI. Fifth, block groups of the home residence are an imperfect and incomplete way of capturing all of the built environment influences on CRF and BMI. Use of block groups may result in mis-specification of the area unit most relevant to PA, and differences in size may have biased results, although the direction is unknown. In addition, areas around the workplace, school or other relevant addresses were not assessed. At the same time, we selected block groups because they represent the smallest administrative unit for characterizing the neighborhood features that are most relevant for influencing PA around one's home. Finally, the cross-sectional study design limits causal inferences. Nevertheless, this study advances the analysis of associations between built environment, PA and obesity, because it includes objectively measured CRF as an outcome variable and because of the availability of information concerning the built environment at a relatively fine geographic scale.

In summary, neighborhood characteristics hypothesized to support more PA and less driving were associated with higher levels of CRF and lower BMI. Moreover, the effects were modified by age. Further research on the relationship between neighborhood environments and CRF in more diverse study populations and environments could help explain mechanisms linking health and neighborhood characteristics.

Acknowledgments

This study was supported in part by an American Cancer Society Mentored Research Scholar Grant (MRSG-07-016-01-CPPB), the Applied Research Program of the National Cancer Institute, 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 Aerobics Center Longitudinal Study, the Cooper Clinic physicians, nurses, and technicians who collected the clinical data, and The Cooper Institute for maintaining the database, especially Beth Wright. We also thank Dr. Larry Frank for his insights when conceptualizing this study, Drs. William Haskell, Ross Brownson, and Richard Troiano for their critical review comments, and Todd Gibson of IMS Inc and Christine Marx for furnishing the Census data and maps.

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Highlights

- This US multilevel study was the first to examine associations between neighborhood walkability and cardiorespiratory fitness.
- Neighborhood walkability was associated with higher levels of cardiorespiratory fitness and lower BMI.
- The associations between neighborhood walkability factors and cardiorespiratory fitness and BMI were moderated by age.

Figure 1.
Distribution of study participants by block group

Figure 2.
Distribution of the *traditional core* factor by block group

Figure 3.

Interaction between the *traditional core* neighborhood factor and age ^a on cardiorespiratory fitness in multivariate models ^b among women (n=5,017) and men (n=11,526)

^a Ages presented are the mean age (46 years) and plus and minus 2 SD (66 and 26 years, respectively)

^b Adjusted for individual-level age, examination year, BMI, and block group-level percent non-Hispanic Black, percent Hispanic, and percent below 200% poverty level. All continuous covariates were grand-centered at the mean value and categorical covariates at the reference level. The parameter estimates for the traditional core factor at the mean age were 0.080 and 0.051 for women and men, respectively. The parameter estimates for the interaction term with age were -0.003 and -0.006 for women and men, respectively. Therefore, the dependence of the effect of *traditional core* on age among women, for example, is represented as $[0.080 - 0.003 * (\text{age} - \text{mean age})] * \text{traditional core}$.

Figure 4.

Interaction between the *traditional core* neighborhood factor and age^a on body-mass index in multivariate models^b among women (n=5,017) and men (n=11,526)

^a Ages presented are the mean age (46 years) and plus and minus 2 SD (66 and 26 years, respectively)

^b Adjusted for individual-level age, examination year, participation in outdoor physical activity, and CRF and block group-level percent non-Hispanic Black, percent Hispanic, and percent below 200% poverty level. All continuous covariates were grand-centered at the mean value and categorical covariates at the reference level. The parameter estimates for the *traditional core* factor at the mean age were -0.199 and -0.216 for women and men, respectively. The parameter estimates for the interaction term with age were -0.014 and -0.011 for women and men, respectively. Therefore, the dependence of the effect of *traditional core* on age among women, for example, is represented as $[-0.199 - 0.011 * (\text{age} - \text{mean age})] * \text{traditional core}$.

Table 1

Rotated factor pattern from principal components analysis of neighborhood variables

	Factor 1^a	Factor 2^a	Factor 3^a
Eigenvalue	4.400	3.065	1.703
Percent	33.9	23.6	13.1
Cumulative Percent	33.9	57.4	70.5
Block group variable			
Median Year Structure Built	−0.0953	0.8787	0.2852
% of units built before 1950	0.0712	−0.7170	−0.3378
% of units built in 1970 or later	−0.1238	0.8382	0.2559
% of commutes <20 minutes	−0.2616	−0.7376	0.2058
% of commutes ≥35 minutes	0.2905	0.7092	−0.2112
Population density	−0.4661	−0.0622	−0.1807
% of units that are 1, detached	0.9392	−0.0436	0.1112
% of units ≥5 attached	−0.9349	0.0652	−0.1182
% of units owner occupied	0.9418	0.0887	0.1427
Median number of rooms	0.8279	0.1186	0.1077
% of commutes by car, truck or van	0.1238	0.1373	0.8862
% of commutes by public transportation	−0.2015	0.0435	−0.7392
% of commutes by walk or bike	−0.2645	−0.2181	−0.6388

^aScores for factors 1–3 were generated and reverse-coded for ease of interpretation so that higher values corresponded with higher predicted levels of walkability. Reverse-coded factor 1 was named “high density;” reverse-coded factor 2 was named “traditional core;” and reverse-coded factor 3 was named “non-auto commuting.”

Table 2

Characteristics of the study population

Characteristic	Women % or Mean (SD)	Men % or Mean (SD)	<i>p</i> -value
N	5017	11526	
Age group			
18–39	27.4	23.2	<0.0001
40–49	37.6	40.7	
50–59	24.3	25.8	
60–90	10.7	10.3	
Ethnicity			
White	69.8	67.4	<0.0001
Other	5.2	3.6	
Missing	24.9	28.9	
Years of education			
7–12	13.8	8.4	<0.0001
13–16	37.4	31.0	
17–20	15.6	24.4	
Missing	33.2	36.1	
Participated in any outdoor physical activity (walking, jogging, bicycling) in the past 3 months	70.5	64.2	<0.0001
Maximal METs	6.8 (1.8)	11.5 (2.0)	<0.0001
BMI (kg/m ²)	24.2 (4.7)	27.5 (4.2)	<0.0001

Table 3

Distribution of Census block-group variables (n=4,501 block groups)

Census Block Group Variable	Min	Median	Max	State of Texas	
				Mean (SD)	Mean (SD) ^a
Median Year Structure Built	1939	1977	1999	1974.2 (13.8)	1964.0 (125.3)
% of units built before 1950	0.0	1.4	96.1	10.3 (19.1)	14.6 (17.6)
% of units built in 1970 or later	0.0	78.0	100.0	65.3 (33.8)	55.3 (31.1)
% of commutes <20 minutes	0.0	43.1	100.0	46.4 (18.4)	47.2 (18.6)
% of commutes ≥35 minutes	0.0	14.9	70.7	17.2 (12.0)	18.2 (12.1)
Population density (persons/square mile)	0.4	1,106.2	22,281.7	1,290.7 (1,243.2)	1,364.1 (1,546.7)
% of units that are one-unit, detached	0.0	80.8	100.0	71.1 (30.0)	68.5 (27.0)
% of units that are ≥5, attached	0.0	1.0	100.0	16.7 (25.9)	14.1 (23.5)
% of units that are owner-occupied	0.0	80.8	100.0	70.9 (26.5)	65.8 (24.9)
Median number of rooms	1.3	5.8	9.1	5.9 (1.4)	5.1 (1.1)
% of commutes by car, truck or van	9.3	93.8	100.0	92.4 (6.8)	91.6 (8.0)
% of commutes by public transportation	0.0	0.0	70.6	1.3 (3.0)	2.1 (4.8)
% of commutes by walk or bike	0.0	0.6	77.8	1.8 (4.2)	2.4 (4.7)
% White	0.9	90.0	100.0	85.8 (14.0)	71.0 (23.3)
% African American	0.0	1.9	95.1	5.3 (9.9)	12.0 (20.5)
% Hispanic	0.0	6.8	100.0	12.1 (16.1)	31.5 (30.0)
% below 200% poverty	0.0	13.3	100.0	18.3 (16.1)	37.9 (21.9)
Median family income (in year 2000 USD)	\$2,499	\$65,968	\$200,001	\$71,879 (\$33,304)	\$46,808 (\$25,836)

^aMean and standard deviation of all block groups in Texas from the US Census 2000. The number of block groups ranged from N=14,401 to 14,463 depending on the variable.

Table 4
Association between neighborhood walkability factors and cardiorespiratory fitness[†]

Walkability Factors	Women (n=5,017)			Men (n=11,526)		
	Model 1	Model 2	Model 3	Model 1	Model 2	Model 3
Traditional core	0.113*** (0.060,0.165)	0.082*** (0.042,0.122)	0.062** (0.024,0.101)	0.107*** (0.064,0.149)	0.056*** (0.025,0.088)	0.042*** (0.012,0.072)
High density	-0.003 (-0.057,0.052)	0.005 (-0.041,0.051)	0.001 (-0.043,0.045)	-0.030 (-0.074,0.015)	0.013 (-0.023,0.050)	0.002 (-0.033,0.036)
Non-auto commuting	0.042 (-0.030,0.115)	0.033 (-0.022,0.088)	0.031 (-0.022,0.084)	0.104*** (0.052,0.155)	0.064** (0.025,0.104)	0.048* (0.010,0.085)
Variance between neighborhoods	0.266	0.075	0.061	0.289	0.067	0.053
Variance within neighborhoods	2.896	1.715	1.621	3.800	2.267	2.090
Percentage of between-neighborhood variation explained [‡]	8	74	79	10	79	83

[†] Data are expressed as beta and (95% confidence interval). Beta is the mean difference in CRF for a one-unit change in the walkability predictor variable. Model 1 includes no covariates. Model 2 is adjusted for individual-level age, examination year, and BMI, and block group-level percent non-Hispanic Black, percent Hispanic, and percent below 200% poverty level. Model 3 is adjusted for the covariates in Model 2, as well as participation in outdoor physical activity (walking, jogging, or bicycling).

[‡] Percentage of variation in block-group mean CRF explained by the individual- and block-group-level variables. Calculated as (between block-group variance from the null model - between block-group variance from the adjusted model)/between block-group variance from the null model.

* p<0.05
** p<0.01
*** p<0.001

Table 5

Association between neighborhood walkability factors and body-mass index[†]

Walkability Factors	Women (n=5,017)				Men (n=11,526)			
	Model 1	Model 2	Model 3	Model 4	Model 1	Model 2	Model 3	Model 4
Traditional core	−0.428*** (−0.561, −0.296)	−0.422*** (−0.558, −0.285)	−0.374*** (−0.508, −0.240)	−0.194** (−0.331, −0.076)	−0.373*** (−0.453, −0.293)	−0.387*** (−0.470, −0.304)	−0.370*** (−0.452, −0.287)	−0.210*** (−0.278, −0.142)
High density	−0.050 (−0.189, 0.089)	−0.185* (−0.343, −0.027)	−0.171* (−0.326, −0.015)	−0.128 (−0.264, 0.008)	−0.099* (−0.183, −0.016)	−0.242*** (−0.338, −0.146)	−0.228*** (−0.323, −0.133)	−0.158*** (−0.236, −0.079)
Non-auto commuting	−0.001 (−0.189, 0.187)	−0.103 (−0.292, 0.087)	−0.098 (−0.285, 0.089)	−0.028 (−0.192, 0.136)	−0.142** (−0.244, −0.042)	−0.252*** (−0.356, −0.147)	−0.232*** (−0.336, −0.128)	−0.100* (−0.186, −0.013)
Variance between neighborhoods	0.925	0.774	0.662	0.462	0.458	0.364	0.332	0.159
Variance within neighborhoods	21.448	20.667	20.339	15.673	16.788	16.608	16.458	11.703
Percentage of between-neighborhood variation explained [‡]	20	33	43	60	28	43	48	75

Data are expressed as beta and (95% confidence interval). Beta is the mean difference in BMI for a one-unit change in the walkability predictor variable. Model 1 includes no covariates, Model 2 is adjusted for individual-level age and examination year and block group-level percent non-Hispanic Black, percent Hispanic, and percent below 200% poverty level, Model 3 is adjusted for the covariates in Model 2, as well as participation in outdoor physical activity (walking, jogging, or bicycling), Model 4 is adjusted for the covariates in Model 3, as well as CRF.

Percentage of variation in block-group mean BMI explained by the individual- and block-group-level variables. Calculated as (between block-group variance from the null model - between block-group variance from the adjusted model)/between block-group variance from the null model.

* p<0.05
** p<0.01
*** p<0.001