Original Contribution

Understanding the Independent and Joint Associations of the Home and Workplace Built Environments on Cardiorespiratory Fitness and Body Mass Index

Christine M. Hoehner, Peg Allen, Carolyn E. Barlow, Christine M. Marx, Ross C. Brownson*, and Mario Schootman

* Correspondence to Dr. Ross C. Brownson, Washington University in St. Louis, One Brookings Drive, St. Louis, MO 63130 (e-mail: rbrownson@wustl.edu).

This observational study examined the associations of built environment features around the home and workplace with cardiorespiratory fitness (CRF) based on a treadmill test and body mass index (BMI) (weight (kg)/height (m)²). The study included 8,857 adults aged 20–88 years who completed a preventive medical examination in 2000–2007 while living in 12 Texas counties. Analyses examining workplace neighborhood characteristics included a subset of 4,734 participants. Built environment variables were derived around addresses by using geographic information systems. Models were adjusted for individual-level and census block group-level demographics and socioeconomic status, smoking, BMI (in CRF models), and all other home or workplace built environment variables. CRF was associated with higher intersection density, higher number of private exercise facilities around the home and workplace, larger area of vegetation around the home, and shorter distance to the closest city center. Aside from vegetation, these same built environment features around the home were also associated with BMI. Participants who lived and worked in neighborhoods in the lowest tertiles for intersection density and the number of private exercise facilities had lower CRF and higher BMI values than participants who lived and worked in higher tertiles for these variables. This study contributes new evidence to suggest that built environment features around homes and workplaces may affect health.

environment design; exercise; geographic information systems; obesity; physical fitness; workplace

Abbreviations: BMI, body mass index; CRF, cardiorespiratory fitness; MET, metabolic equivalent.
on conditions of the home neighborhood (24–30). Focusing on only the residential environment at 1 time point presents methodological limitations given the amount of time spent at other locations (e.g., workplace, school, and shopping and recreational settings) and the spatial mobility of most adults. Several researchers have noted the uncertainty in the extent to which the measured environments deviate from the true causally relevant environments that are exerting influence on health-related outcomes (i.e., the “uncertain geographic context problem”) (31) and the unknown effect of neglecting non-residential environments (i.e., the “residential trap”) (26).

In the current study, we sought to do the following: 1) examine the associations of a comprehensive set of built environment features around the home with measured cardiorespiratory fitness (CRF) and body mass index (BMI) (weight (kg)/height (m)2); 2) assess the extent to which the built environment around the workplace is independently associated with CRF and BMI; and 3) assess how built environment features around both the home and workplace are associated with CRF and BMI. We hypothesized that adults who live and work in the least favorable conditions for physical activity would be less fit and more obese than adults who live and work in more favorable conditions.

MATERIALS AND METHODS

Study design and population

This cross-sectional study analyzed data from the Cooper Center Longitudinal Study (The Cooper Institute, Dallas, Texas). The study includes patients seen at the Cooper Clinic in Dallas, Texas, who came to the clinic for preventive medical examinations and for counseling regarding diet, exercise, and other lifestyle factors associated with chronic disease risk. Most patients were self-referred, although a substantial (but unknown) number were referred by their employers. Participants signed an informed consent for the clinical examinations. The institutional review boards of The Cooper Institute and Washington University in St. Louis (St. Louis, Missouri) approved the current study.

The current analysis includes 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 current study included participants with nonmissing geocodable home addresses in 11 counties of the Dallas–Fort Worth, Texas, metropolitan area and Travis County in the Austin, Texas, metropolitan area, where the majority of participants resided (70%) and where detailed existing data about the built environment (e.g., land use, parks) were freely available. Of the 12,274 participants with geocoded home addresses in the study areas, 172 were excluded on the basis of the following criteria: history of heart attack or stroke, currently pregnant, or being sick for more than 6 weeks in the past year. An additional 1,306 participants were excluded for missing data on BMI or neighborhood built environment measures, and 1,939 more participants were excluded for missing data on covariates (e.g., race/ethnicity, smoking). Because the study population was homogeneous with respect to education, those with missing data were retained with values assigned to a missing category. Analyses involving workplace addresses excluded participants whose workplace addresses were not reported or not geocodable; participants who worked at home, outside the study area, or at the Cooper Aerobics Center, which includes the Cooper Clinic (to eliminate any selection bias); and participants who reported being unemployed or who had missing data on built environment measures in the workplace neighborhood. The final sample for analyses involving the home neighborhood was 8,857 (2,576 women and 6,281 men). Of these, 4,734 were included in analyses of the workplace neighborhood.

Data collection

Clinical examination. At the clinical examination, each patient completed a detailed medical history questionnaire consisting of demographic, health habit, and health history information. Each patient also underwent a maximal exercise treadmill test, a body composition assessment, blood chemistry analysis, blood pressure measurement, and a physical examination by a physician.

Geocoding addresses. All home and workplace addresses of patients living in Texas who had examinations with a maximal treadmill test between January 2000 and June 2007 (n = 16,939) were geocoded by Mapping Analytics, LLC (Rochester, New York). Of these, 89% of home addresses and 75% of workplace addresses were assigned to latitudes/longitudes corresponding to the locations of the addresses. All other addresses with low positional accuracy (i.e., geocoded to zip code centroid, census block group, census tract, or post office box) were excluded.

Neighborhood data. Existing spatial data for built environment features (land use, street connectivity, density, vegetation, sidewalk coverage, speed limits, public and private exercise facilities, and parks) were collected from many sources and prepared by using geographic information systems to generate individual-level variables (Appendix). Several data sets (e.g., land use, parks, and private exercise facilities) required modification and/or correction prior to measures generation because of duplicates, differences in coding between the study regions, or inclusion of irrelevant facilities. For example, the parks data in the Dallas–Fort Worth region required the identification of topological errors, the creation and application of inclusion and exclusion criteria (e.g., exclusion of cemeteries, zoos), and the use of aerial photography and websites for verification. Details about the data ascertainment and preparation of data sources are available by request.

Measures

CRF and BMI. CRF is an objective measure of physiological changes in response to physical activity (32) and recent physical activity (33); it was determined by a maximal exercise treadmill test by using a modified Balke protocol (34) as described elsewhere (35, 36). Patients were encouraged to give 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 equivalent (MET) values as a standard measure of CRF (37, 38). Time on the treadmill with this protocol is highly correlated with maximal oxygen uptake (VO2max) (r = 0.94 in women (38) and r = 0.92 in men (37)).
**Built environment measures.** Neighborhood measures were created within buffers around home and work addresses (Appendix). Aside from the recreational facilities and proximity measures (i.e., distance measures), all measures were generated within 800-m network polygon buffers around the home and workplace addresses with the theory that these built environment features were more likely to influence physical activity within walking distance of the home or workplace. Smaller network buffers of 400 m were also tested in sensitivity analyses for these measures. Network buffers were generated by using ArcGIS Network Analyst (Esri, Inc., Redlands, California). Recreational facilities measures were created within larger radial (i.e., circular) buffers of 1,600 m, with the theory that this distance represents a close driving distance, does not exclude parks that may be offset from the street network (and therefore excluded from the network buffer), and has been used by others (21, 39). Other buffers sizes (400 m, 800 m, 3,200 m, and 8,000 m) for recreational facility measures were tested in sensitivity analyses. Distance to the closest downtown area (as determined by the address of the city hall) of the 3 principal cities (Austin, Dallas, and Fort Worth, Texas) was used as a rough measure of regional accessibility or sprawl with the idea that regional location may be associated with CRF and BMI, independent of the built environment close to one’s residence, via time spent in an automobile to reach destinations throughout the region (40). Distance to workplace was examined for similar purposes among employed adults (41).

**Covariates.** Age, sex, educational status (less than college, college graduate or higher, or missing), race (white or other because of low numbers in nonwhite race categories), marital status (single, married, or divorced/widowed), the presence of children living in the participant’s household (yes or no), cigarette smoking (never smoked, former smoker, or current smoker), and self-reported physical activity were included as covariates. These represented predictors of CRF, physical activity, and BMI (32, 42–47) and/or were associated with the built environment features in this data set. Self-reported weekly participation in 7 types of moderate to vigorous physical activity over the past 3 months was assessed via self-administered questionnaire. Weekly minutes of moderate to vigorous physical activity were derived by multiplying frequency and duration for each type of physical activity and were weighted by each activity’s assigned METs to yield weekly MET-minutes of moderate to vigorous physical activity (48). In addition, census 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 recommended by others (30).

**Statistical analysis**

Statistical analyses were conducted by using SAS, version 9.3, software (SAS Institute, Inc., Cary, North Carolina). To account for clustering of participants’ residences within census block groups, we used generalized estimating equations and simultaneously adjusted for demographic characteristics (age, sex, education, race, marital status, and presence of children in the home), cigarette smoking, BMI (in the CRF models only), and all other built environment variables for the respective location of interest (home or workplace). Multicollinearity was assessed by using the variance inflation factor and by review of β coefficients with and without adjustment for other built environment variables. In addition, because physical activity likely mediates the relationship between the built environment and CRF and BMI, we controlled for weekly MET-minutes of physical activity separately and described how adjustment affected the regression coefficients. Standardized β estimates and 2-sided P values are reported.

Interactions between each of the built environment variables and sex and age were tested to assess whether associations differed between men and women and across age groups. To assess the joint effects of home-workplace environmental features on CRF, we combined tertiles of built environment variables that were significantly associated with CRF around both the home and workplace into 9-category variables ranging from the lowest tertiles to the highest tertiles for both home-workplace built environment variables.

**RESULTS**

The study population was predominantly male, white, college-educated, and married (Table 1). More than half of participants never smoked, 70% met physical activity recommendations, and more than 60% were overweight or obese.

In fully adjusted models, CRF was weakly associated with features of the home neighborhood, including intersection density, area of vegetation, and number of private exercise facilities (Table 2). Distance to the closest city center was negatively associated with CRF. For this model and the subsequent model with BMI as the outcome variable, multicollinearity was not a problem, with all variance inflation factors less than 3 and no meaningful change in β coefficients with and without adjustment for the other built environment variables (data not shown).

In addition, adjustment for weekly MET-minutes of moderate to vigorous physical activity slightly attenuated the associations, and intersection density was no longer statistically significant (P = 0.05; data not shown). Results from sensitivity analyses using different buffer sizes are reported in the table footnotes.

BMI was negatively associated with intersection density and the number of private exercise facilities around the home and positively associated with distance to the closest city center. Only distance to the closest city center retained statistical significance after adjustment for weekly MET-minutes of physical activity (data not shown). No interactions were observed by sex or age.

Features of the built environment in the workplace neighborhood, including intersection density, area of vegetation, average speed limit, and number of private exercise facilities, were positively yet weakly associated with CRF (Table 3). Distance from home to workplace was negatively associated with CRF. Variance inflation factors were higher for built environment variables in the workplace neighborhood models than in the home neighborhood models; yet, the variance inflation factors never exceeded 5, with most variance inflation factors less than 2. Dropping the sidewalk coverage variable (the variable with the highest variance inflation factor) from the final model did not significantly alter associations with correlated variables. Adjustment for weekly MET-minutes of physical activity slightly attenuated associations, but all variables retained statistical significance (data not shown). Results from sensitivity
analyses using different buffer sizes are reported in the table footnotes.

BMI was negatively associated with the average number of features in parks and positively associated with distance to workplace. Adjustment for physical activity slightly attenuated these associations. No interactions were observed by sex or age.

Adjusted joint associations of home-workplace environmental features on CRF and BMI were examined for tertiles of built environment variables that were consistently associated with CRF and BMI around both the home and workplace, namely intersection density and the number of private exercise facilities. The reference groups for all comparisons were participants in the low tertiles for both home and workplace variables. Compared with those in the low tertiles for the number of private exercise facilities around the home and workplace (adjusted mean = 9.92 METs, 95% confidence interval: 9.76, 10.09), adjusted mean CRF levels were 0.39 METs higher among participants in the high-home and high-workplace tertiles (adjusted mean = 10.31 METs, 95% confidence interval: 10.15, 10.48; \( P < 0.001 \)) and 0.17 METs higher among those in the low-home and middle-workplace tertiles (adjusted mean = 10.09 METs, 95% confidence interval: 9.92, 10.26; \( P < 0.05 \)) (Figure 1A) for the number of private exercise facilities. Adjusted mean BMI levels were significantly lower among those in the high tertiles of private exercise facilities around the workplace across all home tertiles (\( P < 0.05 \)) and among those in the high-home and low-workplace tertiles for the number of private exercise facilities (\( P < 0.05 \)) (Figure 1B).

The patterns were similar for intersection density (Figure 2). Compared with participants in the low tertiles for intersection density around both the home and workplace, those in the middle and high tertiles for intersection density in the workplace neighborhood, regardless of the intersection density in the home neighborhood for all but 1 stratum (middle-workplace and high-home tertiles), had higher mean CRF levels (all \( P < 0.05 \)) (Figure 2A). Adjusted mean BMI values were significantly lower among all home and workplace tertiles of intersection density (\( P < 0.05 \)) except among those in the low-home, middle-workplace tertiles and those in the middle-low-home, low-workplace tertiles of intersection density (Figure 2B).

**DISCUSSION**

To our knowledge, this study was the first to document the independent and joint associations of detailed objective measures of the built environment around both the home and workplace with measured CRF and BMI. Higher street connectivity, the number of private exercise facilities, and neighborhood vegetation around both the home and workplace were independently associated with higher levels of CRF. Higher street connectivity and number of private exercise facilities around the home were associated with lower BMI. In addition, the location of one’s home in the region was independently predictive of CRF and BMI. All else being equal, 2-standard deviation differences in intersection density (2 standard deviations = 26.0) and in the number of private recreational facilities (2 standard deviations = 7.3) were associated with 0.18 and 0.21 differences in VO\(_{2}\)\(_{\text{max}}\), respectively, and 0.36 and 0.34 differences in BMI, respectively (equivalent to approximately 1.0 kg for women and 1.1 kg for men of the sample mean heights). Effect sizes were similar for these built environment variables around the workplace. These effect sizes could translate into meaningful effects at a population level.

Associations with features of the workplace neighborhood, specifically intersection density, the number of private exercise facilities, and vegetation, suggest that the built environment beyond the home neighborhood may exert independent...
effects on health. Among the sparse research on workplace and residential neighborhoods, 1 study of 148 adults reported significant associations with the home and workplace built environments for measures of physical activity occurring within the home and workplace buffers, as derived from global positioning system monitors and accelerometers, but not for total the home and workplace buffers, as derived from global positioning system monitors and accelerometers, but not for total

Table 2. Association Between Built Environment Characteristics Around the Home, Cardiorespiratory Fitness, and Body Mass Index, a Cooper Center Longitudinal Study (n = 8,857), Dallas-Fort Worth and Austin, Texas, 2000–2007

<table>
<thead>
<tr>
<th>Built Environment Variable</th>
<th>Cardiorespiratory Fitness a,b,x</th>
<th>Body Mass Index a,b,x</th>
</tr>
</thead>
<tbody>
<tr>
<td>Household density (households per hectare)</td>
<td>-0.010 (0.006) 0.07</td>
<td>-0.006 (0.014) 0.64</td>
</tr>
<tr>
<td>Land use mix g</td>
<td>-0.238 (0.176) 0.18</td>
<td>0.582 (0.433) 0.18</td>
</tr>
<tr>
<td>Intersection density (intersections per km²)</td>
<td>0.005 (0.002) 0.02</td>
<td>-0.014 (0.006) 0.01</td>
</tr>
<tr>
<td>Area of vegetation (proportion)</td>
<td>0.423 (0.187) 0.02</td>
<td>-0.593 (0.498) 0.23</td>
</tr>
<tr>
<td>Sidewalk coverage (km)</td>
<td>0.001 (0.003) 0.86</td>
<td>0.003 (0.009) 0.77</td>
</tr>
<tr>
<td>Average speed limit (miles per hour) h</td>
<td>-0.015 (0.002) 0.20</td>
<td>0.026 (0.029) 0.38</td>
</tr>
<tr>
<td>No. of private exercise facilities</td>
<td>0.027 (0.007) &lt;0.01</td>
<td>-0.046 (0.018) 0.01</td>
</tr>
<tr>
<td>No. of public exercise facilities</td>
<td>-0.047 (0.030) 0.11</td>
<td>-0.097 (0.071) 0.17</td>
</tr>
<tr>
<td>No. of parks</td>
<td>-0.003 (0.008) 0.71</td>
<td>-0.010 (0.019) 0.61</td>
</tr>
<tr>
<td>Average no. of features in parks</td>
<td>-0.028 (0.023) 0.22</td>
<td>0.089 (0.065) 0.17</td>
</tr>
<tr>
<td>Distance to closest park with trail (km)</td>
<td>-0.012 (0.016) 0.44</td>
<td>0.009 (0.046) 0.85</td>
</tr>
<tr>
<td>Distance to closest city center (km)</td>
<td>-0.005 (0.002) 0.02</td>
<td>0.021 (0.005) &lt;0.01</td>
</tr>
</tbody>
</table>

Abbreviation: SE, standard error.

a Weight (kg)/height (m)².

b Adjusted for sex, age, marital status, children in home, educational status, smoking status, body mass index, census block group—level percent below 200% poverty, percent black, percent Hispanic, and all other built environment variables.

c In sensitivity analyses, associations with recreational facility variables were slightly attenuated when using larger buffer sizes (i.e., 3,200 m, 8,000 m) with the exception of parks, which became weakly positively associated with cardiorespiratory fitness when using 8,000-m buffers (β = 0.003; P = 0.049). Negative associations with the number of public exercise facilities became significant when using other buffer sizes (i.e., 400 m, 800 m, 3,200 m, and 8,000 m), again with weaker associations observed as buffer sizes increased. Associations with the other nonrecreational facility variables measured by using 400-m network buffers were either not significant or slightly weaker than when measured by using 800-m buffers.

d Adjusted for sex, age, marital status, children in home, educational status, smoking status, census block group—level percent below 200% poverty, percent black, percent Hispanic, and all other built environment variables.

e In sensitivity analyses, applying other buffer sizes to the built environment variables did not appreciably change the results for body mass index. Associations with the number of private exercise facilities and intersection density were weaker or not significant with other buffer sizes, and none of the other variables became significant after using a different buffer size.

f P values based on Wald test statistic from generalized estimating equations.

g The entropy index (residential, commercial, institutional, office) ranges from 0 to 1, where 0 = no mix and 1 = equal mix.

h One mile = 1.61 km.

Possible mechanisms for associations between the workplace built environment and health may be that adults are more physically active when the workplace environment provides opportunities for physical activity, particularly in this study population of healthy adults; alternatively, it could be that these built environment characteristics represent more urban environments, in which services are within closer proximity, requiring less driving and, thus, less time sitting. Altogether, more research is warranted to clarify the mechanisms by which characteristics of the workplace neighborhood affect CRF and BMI.

Elements of the built environment associated with both active transportation (intersection density) and with leisure-time physical activity (private exercise facilities) were independently associated with CRF and BMI, which is generally consistent with findings from cross-sectional and quasi-experimental studies (9, 52, 53). Also, associations between

regional location and commute distance parallel those from studies of urban sprawl (54), regional accessibility (40), and long commutes (41, 55), suggesting that the adverse effects of urban sprawl on health are attributable to more than the near-neighborhood built environment characteristics, but also reflect longer distances to commercial and employment destinations (7). This study is among the few that have examined associations between neighborhood greenness by using the Normalized Difference Vegetation Index and physical activity (49, 56) or obesity (57).

The lack of evidence for multicollinearity among built environment variables, as well as the lack of association between some built environment features and CRF and BMI, were unexpected. The Texas metropolitan areas in this study, and many others in the United States, are unlike highly dense US and European cities, and thus features like high street connectivity and land-use mix do not coexist, contrary to what has been observed by others (58). Moreover, the levels of land use mix, household density, and sidewalks that are needed to affect physical activity and obesity may be insufficient to overcome the automobile-oriented transportation design and culture typical of the study regions. The lack of associations with proximity and density of parks may be attributable to the lack of information on quality of parks, which may be more influential than mere presence and proximity of parks. In addition, access to private exercise facilities, which may be visited more regularly and where physical activity can be of higher intensity, may contribute more to CRF and BMI in this study population. Other features, such as traffic speed, may have been too crude to detect associations with CRF and BMI.

Testing associations by using different buffer sizes indicated that application of different buffer sizes can alter the strength and

### Table 3. Association Between Built Environment Characteristics Around the Workplace, Cardiorespiratory Fitness, and Body Mass Index, a Cooper Center Longitudinal Study, Dallas-Fort Worth and Austin, Texas, 2000–2007

<table>
<thead>
<tr>
<th>Built Environment Variable</th>
<th>Cardiorespiratory Fitnessb,c</th>
<th>Body Mass Indexa,d,e</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>β (SE)</td>
<td>P Valuef</td>
</tr>
<tr>
<td>Household density (households per hectare)</td>
<td>−0.006 (0.005)</td>
<td>0.22</td>
</tr>
<tr>
<td>Land use mixg</td>
<td>−0.310 (0.168)</td>
<td>0.07</td>
</tr>
<tr>
<td>Intersection density (intersections per km²)</td>
<td>0.007 (0.002)</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Area of vegetation (proportion)</td>
<td>0.761 (0.187)</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Sidewalk coverage (km)</td>
<td>−0.003 (0.006)</td>
<td>0.58</td>
</tr>
<tr>
<td>Average speed limit (miles per hour)h</td>
<td>0.032 (0.010)</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>No. of private exercise facilities</td>
<td>0.019 (0.006)</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>No. of public exercise facilities</td>
<td>0.000 (0.031)</td>
<td>1.00</td>
</tr>
<tr>
<td>No. of parks</td>
<td>0.005 (0.004)</td>
<td>0.25</td>
</tr>
<tr>
<td>Average no. of features in parks</td>
<td>−0.000 (0.000)</td>
<td>0.27</td>
</tr>
<tr>
<td>Distance to closest park with trail (km)</td>
<td>−0.001 (0.038)</td>
<td>0.97</td>
</tr>
<tr>
<td>Distance to workplace (km)</td>
<td>−0.006 (0.002)</td>
<td>&lt;0.01</td>
</tr>
</tbody>
</table>

Abbreviation: SE, standard error.

b Adjusted for sex, age, marital status, children in home, educational status, smoking status, body mass index, census block group–level percent below 200% poverty, percent black, percent Hispanic, and all other built environment variables.

c In sensitivity analyses, associations with the number of private exercise facilities were attenuated when using larger buffer sizes. Associations with the other built environment variables assessed at different buffer sizes were either slightly weaker or not significant, with the exception of land use mix, which became significantly negatively associated with cardiorespiratory fitness when assessed by using 400-m network buffers (β = −0.389; P = 0.009).

d Adjusted for sex, age, marital status, children in home, educational status, smoking status, census block group–level percent below 200% poverty, percent black, percent Hispanic, and all other built environment variables.

e In sensitivity analyses, applying larger buffer sizes to the recreational facilities variables (i.e., 3,200 m, 8,000 m) resulted in weaker, but significant, negative associations with the number of private exercise facilities (for 3,200 m, β = −0.025, P = 0.001; for 8,000 m, β = −0.012, P < 0.001), and positive associations with the number of public recreational facilities (for 3,200 m, β = 0.104, P = 0.016; for 8,000 m, β = 0.038, P = 0.017). In addition, when using 400-m network buffers around the workplace, land use mix (β = 1.050, P = 0.005) and sidewalk coverage (β = −0.091, P = 0.044) became significantly associated with body mass index.

f Values based on Wald test statistic from generalized estimating equations.

g The entropy index (residential, commercial, institutional, office), ranges from 0 to 1, where 0 = no mix and 1 = equal mix.

h One mile = 1.61 km.
Figure 1. A) Mean cardiorespiratory fitness levels with 95% confidence intervals, and B) mean body mass index with 95% confidence intervals, by tertiles of the number of private exercise facilities around the home and workplace, adjusted for all demographic variables, educational status, smoking status, body mass index (A only), distance from home to workplace, census block group variables, and all other home and workplace built environment variables, Cooper Center Longitudinal Study, Dallas-Fort Worth and Austin, Texas, 2000–2007 (n = 4,734). MET, metabolic equivalent.
Figure 2. A) Mean cardiorespiratory fitness levels with 95% confidence intervals, and B) mean body mass index with 95% confidence intervals, by tertiles of intersection density around the home and workplace, adjusted for all demographic variables, educational status, smoking status, body mass index (A only), distance from home to workplace, census block group variables, and all other home and workplace built environment variables, Cooper Center Longitudinal Study, Dallas-Fort Worth and Austin, Texas, 2000–2007 (n = 4,734). MET, metabolic equivalent.
significance of some associations. Two major themes emerged. First, the strength of associations with recreational facilities generally became weaker with the use of larger buffer sizes. Second, the significance of some variables was sensitive to the choice of buffer size, particularly the number of public exercise facilities and land use mix. The direction of associations with these 2 variables was opposite than expected, suggesting that this study region may differ from others that have been studied previously, or that these variables serve as proxies to unmeasured built or social environment features that are adversely associated with physical activity.

Several limitations deserve mention. First, this study did not take into account other places where people spend time; more studies that characterize environmental exposures within individuals’ activity spaces are needed (59, 60). Second, we lacked information on the amount of time spent at home or in the workplace, the length of residence or employment, and the location of physical activity. The incorporation of time in measures of exposure will greatly enhance the understanding about how the geographies of life affect health (31, 61). Third, the study participants were well-educated and predominantly white and, therefore, are not representative of the general population or high-risk subpopulations. Replication in diverse samples is needed. Fourth, the use of census block groups rather than individual buffers for census-derived racial composition and poverty variables introduced inconsistencies in the spatial scales used. Fifth, the cross-sectional design limits causal inference, leaving open the possibility that physically active individuals may choose homes in neighborhoods that support these preferences; however, self-selection may contribute less to the significant associations observed with built environment factors in the workplace neighborhoods.

In conclusion, this large observational study found that features of the built environment related to walkability, access to places to exercise, and sprawl were associated with measured CRF and BMI. Moreover, this study contributed new evidence to suggest that the effects of the built environment on health may not be limited to where a person lives but may be extended to include the workplace neighborhood.

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Conflict of interest: none declared.

REFERENCES


(Appendix follows)
<table>
<thead>
<tr>
<th>Broad Built Environment Domain</th>
<th>Specific Variable</th>
<th>Operational Definition</th>
<th>Data Source</th>
<th>Buffer Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Land use</td>
<td>Land use mix</td>
<td>Entropy index (residential, commercial, institutional, office), range 0–1, where 0 = no mix and 1 = equal mix (^{26})</td>
<td>NCTCOG 2005 and City of Austin 2003 land use inventories(^ 2)</td>
<td>800-m, network</td>
</tr>
<tr>
<td>Street connectivity</td>
<td>Intersection density</td>
<td>No. of (\geq 4)-way intersections per km(^2)</td>
<td>Esri StreetMap 2005 (Esri, Inc., Redlands, California)</td>
<td>800-m, network</td>
</tr>
<tr>
<td></td>
<td>Gross household density</td>
<td>No. of housing units per hectare of total buffer area, apportioned from block groups</td>
<td>US Census Bureau (2000)</td>
<td>800-m, network</td>
</tr>
<tr>
<td>Recreational facilities</td>
<td>No. of parks</td>
<td>No. of parks</td>
<td>NCTCOG 2007 and City of Austin 2005 park inventories(^ 3)</td>
<td>1,600-m, radial</td>
</tr>
<tr>
<td></td>
<td>Distance to closest park with a trail</td>
<td>Distance from home or workplace address to nearest park with a trail</td>
<td>NCTCOG 2007 and City of Austin 2005 park inventories along with local parks-and-recreation websites and personal correspondence</td>
<td>Not applicable</td>
</tr>
<tr>
<td></td>
<td>Average no. of park features</td>
<td>Average no. of facilities in parks within buffer among the following 7 types: ball field, trail, exercise area, playground, tennis court, swimming pool, and recreational center</td>
<td>Parks-and-recreation websites, municipal websites, and personal correspondence for Dallas-Fort Worth (2008–2009) and parks inventories for the City of Austin (2007)</td>
<td>1,600-m, radial</td>
</tr>
<tr>
<td></td>
<td>No. of public recreational facilities</td>
<td>No. of municipally operated recreational centers</td>
<td>Parks-and-recreation websites, municipal websites, and personal correspondence for Dallas-Fort Worth (2008–2009) and parks inventories for the City of Austin (2007)(^ 3)</td>
<td>1,600-m, radial</td>
</tr>
<tr>
<td></td>
<td>No. of private exercise facilities</td>
<td>No. of facilities including the following types: dance, fitness, tennis/ racquetball, swimming, martial arts, yoga, country clubs, and YMCA(^ s)</td>
<td>Dun &amp; Bradstreet, Inc. (Short Hills, New Jersey) archival business listings for years 2002, 2004, and 2006; YMCA corporate offices for locations of YMCA(^ s) (2009)</td>
<td>1,600-m, radial</td>
</tr>
<tr>
<td>Sidewalks</td>
<td>Sidewalk length</td>
<td>Total length of sidewalks</td>
<td>NCTCOG 2007 planimetric data and City of Austin 2006 sidewalk data</td>
<td>800-m, network</td>
</tr>
<tr>
<td>Traffic speed</td>
<td>Average speed</td>
<td>Average speed limit of road segments, excluding driveways or other roads with speeds &lt;10 miles/hour(^ 4)</td>
<td>Esri StreetMap data</td>
<td>800-m, network</td>
</tr>
<tr>
<td>Vegetation</td>
<td>Proportion vegetation</td>
<td>Proportion of area that is vegetation. Area was classified as vegetation if the Normalized Difference Vegetation Index exceeded the county-specific threshold (range, 0.3–0.6) for each raster pixel</td>
<td>One-meter color-infrared aerial photography from the National Agriculture Imagery Program 2004 (US Department of Agriculture, Washington, DC)</td>
<td>800-m, network</td>
</tr>
<tr>
<td>Regional location</td>
<td>Distance to closest city center</td>
<td>Distance (in km) from home address to closest city center based on the city hall addresses of Dallas, Fort Worth, or Austin, Texas</td>
<td>Municipal websites (2008)</td>
<td>Not applicable</td>
</tr>
<tr>
<td>Commute distance</td>
<td>Distance from home to workplace</td>
<td>Distance (in km, along road network) from home to workplace address</td>
<td>Medical history questionnaire (addresses)</td>
<td>Not applicable</td>
</tr>
</tbody>
</table>

Abbreviation: NCTCOG, North Central Texas Council of Governments.

\(^{26}\) Zero represents a single land use and 1 represents an even mix of each included type of land use.

\(^{3}\) Land use codes were harmonized.

\(^{4}\) Extensive cleaning was performed on the basis of aerial photography and website data.

\(^{5}\) With cross-checking against Dun & Bradstreet listings.

\(^{6}\) Listings were matched to patients’ examinations occurring in 2000–2002, 2003–2004, and 2005–2007, respectively.

\(^{7}\) One mile = 1.61 km.