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Exploring Associations between Physical Activity and Perceived and Objective Measures of the Built Environment

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ABSTRACT *The built environment may be responsible for making nonmotorized transportation inconvenient, resulting in declines in physical activity. However, few studies have assessed both the perceived and objectively measured environment in association with physical activity outcomes. The purpose of this study was to describe the associations between perceptions and objective measures of the built environment and their associations with leisure, walking, and transportation activity. Perception of the environment was assessed from responses to 1,270 telephone surveys conducted in Forsyth County, NC and Jackson, MS from January to July 2003. Participants were asked if high-speed cars, heavy traffic, and lack of crosswalks or sidewalks were problems in their neighborhood or barriers to physical activity. They were also asked if there are places to walk to instead of driving in their neighborhood. Speed, volume, and street connectivity were assessed using Geographic Information Systems (GIS) for both study areas. Locations of crashes were measured using GIS for the NC study area as well. Objective and perceived measures of the built environment were in poor agreement as calculated by kappa coefficients. Few associations were found between any of the physical activity outcomes and perception of speed, volume, or presence of sidewalks as problems in the neighborhood or as barriers to physical activity in regression analyses. Associations between perceptions of having places to walk to and presence of crosswalks differed between study sites. Several associations were found between objective measures of traffic volume, traffic speed, and crashes with leisure, walking, and transportation activity in Forsyth County, NC; however, in Jackson, MS, only traffic volume was associated with any of the physical activity outcomes. When both objective and perceived measures of the built environment were combined into the same model, we observed independent associations with physical activity; thus, we feel that evaluating both objective and perceived measures of the built environment may be necessary when examining the relationship between the built environment and physical activity.*

KEYWORDS *Physical activity, Built environment, Geographic Information Systems (GIS), Perceptions, Objective measures*

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INTRODUCTION

Given that a large percentage of the U.S. population does not engage in sufficient levels of physical activity to confer health benefits as recommended by the U.S. Surgeon General (at least 30 min of physical activity of moderate intensity, on most, preferably all, days of the week),[1,2] lack of physical activity has emerged as a public health priority. In recent years, research has emphasized the role that the physical environment may play in determining whether an individual is active or not.[3–5] It has been conjectured that if an environment is one that discourages healthy behaviors, or encourages unhealthy behavior, it is unreasonable to expect large proportions of the population to make behavior changes for the better.[6–9] Consequently, the built environment, generally defined as those aspects of the environment that are manmade or modified by humans, such as homes, workplaces, and roads,[10] are hypothesized by many as playing a role in the high levels of physical inactivity currently observed in the United States.[11]

Studies from the transportation, urban design, and planning literatures[12] generally support the hypothesis that neighborhood environment is associated with physical activity in the form of walking and biking for transport.[11,12] Several cross-sectional studies have measured the built environment objectively using field surveys to obtain measures of sidewalk continuity, street connectivity, ease of street crossing[13,14] and block length.[15] However, the use of field surveys is prohibitive in terms of cost and time, which results in small study areas or sampling of a small fraction of streets within each neighborhood, a potential source of bias. As an alternative, several researchers in the transportation, urban design, and planning fields have utilized Geographic Information Systems (GIS) to objectively measure the built environment over large study areas, using publicly available road networks to measure counts of three- and four-way intersections, median perimeter of blocks, and block length.[16–20] GIS has also been used in correlational analyses evaluating the relationship between land development attributes, such as population density and land use mix, and nonmotorized travel. The 1995 Nationwide Personal Transportation Survey[21] has shown that increased population density is associated with increased travel by walking and cycling and others have shown that nonmotorized commuting is higher in areas of more mixed land use.[22]

In contrast, studies from the public health literature evaluating the relationship between the built environment and physical activity commonly measure the frequency, intensity, and duration of physical activity and generally control for individual factors that may affect physical activity levels. Perceptions of the built environment in these studies are usually the independent factors of interest. A review of the literature identified several studies that evaluated the association between physical activity and built environmental factors such as perceptions of traffic, presence of sidewalks, and destinations within walking distance. Perception of heavy traffic was found not be associated with walking activity in one study[23] nor with meeting recommendations for leisure activity in two studies.[24,25] However, one study did find a positive association between meeting recommendations for leisure activity and perception of heavy traffic.[26] No association between perceived presence of sidewalks and meeting recommendations for leisure activity was reported in two studies of adult women.[24,25] The association between perceptions of destinations within walking distance and physical activity was measured in several different ways with varying results.

Despite the benefits of having obtained better quality measures of physical activity, being able to control for individual-level factors and evaluating perceptions of the built environment, most of the studies, to date, in the public health field have at least two shortcomings. First, although these studies have assessed individual perceptions of the built environment, they have not assessed whether individuals perceive that the built environment is a barrier to physical activity. Second, few of these studies have objectively measured the built environment, and those that have obtained objective measures have either not clearly stated how the objective measures were obtained[27] or have used indirect measures or surrogates.[28–30] Because it is not known whether perception of the built environment has an independent, synergistic, or shared association with the actual environment in relation to physical activity,[12] evaluating the interplay between perceived and actual characteristics of the built environment and how they relate to physical activity is important. Consequently, this study examines the association of physical activity with perceptions of the built environment, perceptions of whether the built environment affects one's physical activity, and the objectively measured built environment using GIS. Objective measures were collected for those aspects of the built environment hypothesized to have an effect on physical activity behavior: traffic speed, traffic volume, street connectivity, and crashes involving pedestrians and bicyclists.

METHODS

Source Population

A cross-sectional study was conducted from January to July 2003 to examine potential environmental barriers and enablers to physical activity. A random-digit-dialed phone survey of the noninstitutionalized adult population was conducted in two geographically defined communities (Forsyth County, NC and the city of Jackson MS). Forsyth County consists of a central urban area (Winston Salem) and several smaller rural regions. Jackson, MS is a metropolitan statistical area that is primarily urban in nature. A disproportionate sampling strategy was adopted for the Forsyth County, NC sample frame to ensure representation for areas outside of the Winston–Salem metropolitan area within the county. Despite using Behavioral Risk Factor Surveillance System (BRFSS) protocols[31] of up to 15 call attempts for each sampled phone number distributed across weekday, weeknight, and weekends, the Council of American Survey Research Organizations response rate, which reflects both the degree of cooperation and the efficiency of the telephone sampling, was not as high as expected: overall 20.2%, rural Forsyth County 24.0%, Winston Salem 24.5%, and Jackson 16.9%. The average length of the telephone interview was 27 min and was written at an eight grade reading level (±1.5 grades) as calculated with the SMOG readability formula.[32] A test–retest survey of a sample of 106 survey respondents was conducted to assess the reliability of physical activity measures and perceived environmental measures.[33,34]

Physical Activity Measures

Information on leisure activity, walking, and transportation activity were collected as part of the phone survey and assessed separately because the environmental factors affecting these forms of activity likely differ.[35] Leisure activity was assessed using questions from the *BRFSS* module on physical activity used from 1986–2000.[36,37] Respondents were categorized based on the type, frequency, duration, and intensity of the two most common physical activities they participated in during the past month. Intensity was derived from the respondent's age, sex, and the published metabolic equivalents of the specific leisure activities the respondent reported.[37] Leisure activity was coded into three levels based on the 1996 U.S. Surgeon General's Report, American College of Sport Medicine, and Centers for Disease Control and Prevention recommendations: (1) meets recommendations, (2) insufficiently active, and (3) inactive.[1,37] Respondents reporting at least 30 min of moderate intensity leisure activity on ≥5 days of the week or 20 min of vigorous intensity leisure activity on ≥3 days/week were categorized as meeting recommendations for leisure activity. Respondents who reported some moderate or vigorous intensity leisure activity but not enough to meet recommendations were categorized as being insufficiently active based on leisure activity, and those who did not report any leisure activity were coded as inactive based on leisure activity. Furthermore, because we were interested in the association between physical activity and the neighborhood environment, we also defined an analogous three-level outdoor leisure activity variable by taking into account only those leisure activities likely to be performed outdoors and near one's home based on responses to questions on whether respondents had places to be physically active (indoors, outdoors, or both) and where these activities were usually performed (near home, near work, near home and work, or some other place). We did not exclude the small percentage (3%) of persons who reported only indoor places to be physically active and performed leisure physical activity when creating the outdoor outcome variable because it was hypothesized that the reason participants felt they did not have places outdoors to be physically active was a reflection of both the perceived and actual (observed) built environment in their neighborhood.

Walking for any purpose was assessed using questions from the 2001 optional *BRFSS* module on physical activity[31,38] and respondents were categorized into three activity categories based on the aforementioned physical activity guidelines. Respondents who reported walking for at least 30 min/day on five or more days in a *usual* week were coded as meeting recommendations through walking. Respondents who reported any walking, but not enough to meet recommendations, were coded as having insufficient activity based on walking, and respondents who reported no walking in a *usual* week were coded as inactive.

Transportation activity was assessed with one question that asked the number of minutes spent walking or bicycling for transportation purposes, such as to and from work and shopping.[39,40] Respondents were categorized as active for transportation activity if they spent at least 10 min in a usual week engaging in transportation activity.

Perceived Measures

Perception of neighborhood environment was assessed with questions on whether high-speed traffic, heavy traffic, lack of crosswalks, and lack of sidewalks were a problem in one's neighborhood (strongly agree, agree, disagree, and strongly disagree). Results from the test–retest reliability survey[33] indicated moderate to substantial reliability for these questions on a subset of participants: high-speed traffic (intraclass correlation coefficient [ICC]=0.65, 95% confidence interval [CI] 0.52–0.74), heavy traffic (ICC=0.67, 95% CI 0.54–0.76), lack of crosswalks or traffic signals (ICC=0.45, 95% CI 0.29–0.59), and lack of sidewalks (ICC=0.57, 95% CI 0.43–0.69). In addition, respondents were asked if these same factors were barriers to being physically active (yes/no). Reliability of these measures on a subset of participants was also moderate to substantial: high-speed traffic (kappa=0.67, 95% CI 0.55–0.76), heavy traffic (kappa=0.66, 95% CI 0.51–0.81), lack of crosswalks or traffic signals (kappa=0.51, 95% CI 0.33–0.70), and lack of sidewalks (kappa=0.49, 95% CI 0.33–0.65). Perception of connectivity, or walkability, was ascertained by asking respondents: "In your community, are there businesses or places where you need to go, such as stores or churches, where you can walk instead of drive? (yes/no)" (referred to as "walkable destinations" from this point). The reliability of this question was substantial (kappa=0.62, 95% CI 0.46–0.78).

Potential confounders included self-reported sociodemographic information collected from the survey: age (18–29, 30–44, 45–64, or 65 and above), gender, marital status (partnered or unpartnered), work activity (not employed, mostly sitting or standing, mostly walking, or heavy labor or physically demanding work), number of children in household (none, one, two, or more than two), education (less than high school, high school graduate, some college, or college graduate), race/ethnicity (non-Hispanic white, non-Hispanic Black, or others), household income (<\$25,000, \$25,000– \$50,000, or ≥ \$50,000), and availability of motor vehicle for personal use (very often, often, sometimes, or never). The survey also asked about general health (excellent, very good, good, fair, or poor), which was considered as a potential confounder as well.

Objective Measures

Objective measures of the environment were collected and mapped using GIS software. Of the 1,659 participants who agreed to complete the survey, 1,482 were geocoded at the address level. The neighborhood was defined by creating a one-mile radius around each geocoded participant's address because the survey defined the participant's neighborhood as "a 20-minute walk, or 1 mile" from his or her home. Smaller radii of a half-mile and an eighth-mile were also evaluated, as it was hypothesized that a smaller area around one's home might be more influential in an individual's choice to be physically active. Where possible, objective measures of the built environment were collected for the study area plus the half-mile surrounding the study area to obtain measures for all study participants, including those whose home address was on or close to the study area boundary, and eliminate any border effects.

Traffic Speed As a surrogate for actual speed we used the posted speed limits for each road obtained as part of a road network file from the Forsyth County Tax Office for the North Carolina study area. In the Jackson, MS study area the road network was obtained as a PolyLine file from the U.S. Census Bureau Topologically Integrated Geographic Encoding and Referencing (TIGER) database of selected geographic and cartographic information.[41] Each road segment of the TIGER/Line network was assigned a speed based on posted speed limit information from the Traffic Engineering Division of Jackson, MS and the City Ordinance Book from Jackson, MS. Using the Spatial Analyst extension in ArcView,[42] the PolyLine road networks were converted to a grid using the speed limit variable to categorize the grid. We were then able to summarize the mean speed, maximum speed, and majority speed (the speed occurring most frequently on the road segments within a buffer) for each neighborhood surrounding the respondent's home address.

Traffic Volume Volume was obtained from the 2001 Annual Average Daily Traffic (AADT) counts for both study areas. Annual Average Daily Traffic is conducted mechanically using tubes laid across the road over a 24-h period in Forsyth County, NC and a 48-h period in Jackson, MS. A file containing the geocoded locations and volume counts of 1,513 AADT readings during 2001 was obtained from the City of Winston Salem, NC Department of Transportation (DOT). An additional 42 AADT locations were hand-geocoded from paper maps obtained from the NC DOT for the half-mile surrounding the study area. Paper maps of the AADT counts were obtained from the Mississippi DOT for the study area and the half mile surrounding the study area and the location of these 370 traffic count locations were geocoded by hand using the TIGER/Line road network.

Because traffic volume was not measured on every road within the two study areas, we interpolated values for those road sections without counts by creating a statistical surface in ArcView using the Spatial Analyst Extension.[42] Inverse distance weighting of the point shapefile containing the locations of known traffic counts was used to interpolate a traffic volume value to every point in the study area. The maximum and average traffic volume was calculated for each of the three neighborhood sizes surrounding each respondent's home address using the summarized zone's option in the Spatial Analyst[42] Extension of ArcView.

Street Connectivity Street connectivity was measured in several ways: the average number of road segments (link count), ratio of road segments to intersections (link–node ratio), average length of road segments, the density of ≥3-way intersections, and census block density. These measures are all indicators of connectivity and of the distance from home locations to destinations.[19,43] These measures, except census block density, were calculated using the TIGER/Line road networks for the study areas plus the half mile surrounding the study area. The TIGER/Line file, which consists of all road segments in the study area, was dissolved into one continuous segment using the Geoprocessing Extension in ArcView. The Edit Tools Extension[44] was then used to create a point at every intersection and at the end of all roads. In ArcView, the Count Points in Polygon extension[45] was used to count the number of ≥3-way intersections and the number of ≤2-way intersections (e.g., dead-end streets or cul-de-sacs). These two values were used to create the density of ≥3-way intersections. A new road network file consisting of segments corresponding to the distance between intersections and/or the end of the road was created using the Point and PolyLine Tools Extension,[46] the point theme containing all of the ≥3-way and ≤2-way intersections, and the dissolved road network. The road segments or links created in this newly segmented road network were joined spatially with each neighborhood buffer in ArcGIS[47] to calculate the average length of each link and the number of links within each neighborhood. The ratio of the number of links to the number of ≥3-way intersections was then calculated in SAS version 8.2.[48] To calculate census block density, shapefiles containing the 2000 census blocks for the study areas were obtained from the 2000 Census TIGER/Line data.[41] The polygon file of census blocks was overlaid onto the polygon files of the neighborhood buffers and the number of census blocks intersecting with each neighborhood was calculated using the Xtools Extension in ArcView 3.3.[43,49]

Traffic Crashes Information on the 1,420 traffic crashes involving a pedestrian or bicyclist in Forsyth County, NC was obtained from the University of North Carolina Highway Safety Research Center (HSRC) for the 10-year period from

1993–2002. Crash locations were obtained for a 10-year period to account for the random nature of accidents. Crashes more than 10 years before the survey were not collected because the design of the street network and amount of traffic volume before the early 1990s may be too different to accurately reflect the communities at the time of the telephone survey. Locations of the crashes were hand-geocoded based on the road that the accident occurred on and the distance from the nearest intersections that was provided by HSRC. If a crash occurred on private property (n=52), for instance in a residential driveway, no information was available on the location of the accident and these crashes were excluded from analyses. One thousand one hundred fifty-eight crashes were successfully geocoded from the information obtained from HSRC. An additional 145 crashes were geocoded after obtaining the crash reports of the crashes from the North Carolina Department of Motor Vehicles, resulting in a 95.2% overall match rate. We were unable to obtain similar data for the Jackson, MS study area.

For each buffer under consideration, the number of crashes involving a pedestrian and/or bicyclist was counted around each participant's home address using the Count Points in Polygons Extension[45] in ArcView. To normalize for exposure, the number of crashes counted in each neighborhood was then weighted by the population of the neighborhood and dichotomized into low (≤5 crashes per 1,000 inhabitants) and high (>5 crashes per 1,000 inhabitants) occurrence of crashes. The population density of each neighborhood was calculated using the Calculate Demographics script in ArcView,[50] which assigned the total population from the 2000 U.S. Census proportionately based on the area of intersection of the census block polygons and the respondents' neighborhood.

Statistical Analyses

Guided by an exploratory factor analysis of all the objectively measured speed, volume, and street connectivity variables described above, we created three summary variables describing components of neighborhood street and traffic characteristics using site-specific estimates. Site-specific cut-points were used instead of a standard cut-point for the entire sample because of the differences in measures between the two study areas. Briefly, factor analyses were calculated for both study areas and for each neighborhood size (1-, half- and eighth-mile). Based on the eigenvalue greater than one[51,52] criteria and scree plots, the results generally indicated that maximum, majority, and mean speed loaded onto one factor (speed); mean and maximum volume onto a second factor (volume); and the average number of road segments, ratio of road segments to ≥3-way intersections, census block density, and the density of ≥3-way intersections loaded onto a third factor (street characteristics). The average length of road segments dropped out from the factor analysis. Each variable that loaded onto a given factor was dichotomized into low (below the median) or high (above the median) based on the site-specific median of that variable. These dichotomized variables were summed to create a summary score, which ranged from 0 to the number of variables that loaded onto the factor. These summary scores were then dichotomized to represent a "high" or a "low" score for the corresponding factor based upon approximate median values. The summary scores derived from this factor analysis will be referred to as the speed summary score, volume summary score, and street connectivity/density summary score.

Percent agreement between (1) perception of the built environment and the objectively measured built environment summary variables and (2) perception of the built environment as a barrier to physical activity and the objectively measured built environment summary variables was calculated using kappa statistics. Agreement was categorized according to Landis and Koch's classification[53]: kappa values between 0 and 0.2 are considered poor, 0.2 to 0.4 fair, 0.4 to 0.6 moderate, 0.6 to 0.8 substantial, and 0.8 to 1.0 almost perfect.

Associations between the physical activity outcomes with the (1) perception of the built environment, (2) perception of the built environment as a barrier to physical activity, (3) the objectively measured built environment, and (4) combinations of perceived measures and objective measures were examined with either logistic regression (for binary outcome of transportation activity) or the generalized logits model (for the three-level outcomes of leisure activity, outdoor leisure activity, and walking for any purpose). Potential confounders were identified based on backward elimination with a 10% change in estimate criteria and prior knowledge of the influence each variable had on physical activity. Prevalence estimates were weighted to account for the probability of selection and adjusted with poststratification weights based on 1999 US Census data for age (four categories: 18–29, 30–44, 45–64, and 65 and above) and sex using Sudaan.[54] All other analyses were performed using SAS version 8.2[48] on unweighted data because it was shown that weights have a modest effect on effect estimates.[55]

RESULTS

Sample Characteristics

Of the 1,482 participants for whom we were able to obtain geocodable addresses, 201 reported the presence of health problems or a disability that moderately or severely limited physical activity; an additional 12 did not provide information on disability status and were thus excluded from analyses. The final sample used in analyses consisted of 1,270 respondents, 599 from Jackson, MS and 671 from Forsyth County, NC. The majority of this sample was non-Hispanic White (57.0%) or non-Hispanic Black (38.2%), 9.8% of the respondents considered themselves to be of poor or fair general health. Of the respondents, 26.5% reported no leisure time activity in the past month, 46.1% reported some leisure time activity in the past month, but not enough to meet recommendations, and 27.5% reported leisure time activity in the past month that met the current recommendations for physical activity. When only outdoor leisure activities were considered, a larger percentage of respondents (40.2%) were categorized as being inactive and a smaller proportion were categorized as meeting recommendations for physical activity (16.4%) in the past month. 18.6% of respondents reported not walking for any purpose in a usual week, and 36.2% reported meeting recommendations for physical activity while walking during a usual week. Lastly, only 69.5% of respondents reported engaging in any transportation activity (≥10 min) in a usual week. There were no differences in these characteristics by study area.

Neighborhood Characteristics

Values for objective measures of speed, volume, and street connectivity varied by study area (Table 1). The median value for the mean, majority, and maximum speeds within each respondent's one-mile, half-mile, and eighth-mile neighborhoods was greater in Forsyth County, NC than in Jackson MS, whereas the reverse was true for the median value of mean and maximum volumes. Also, street connectivity

TABLE 1 Median values of the objective measures of the built environment for the one-mile, half-mile, and eighth-mile neighborhoods by study area

	Jackson, MS			Forsyth County, NC		
	one mile	Half mile	Eighth mile	one mile	Half mile	Eighth mile
Mean speed (mph)	28.4	27.3	26.2	35.8	34.8	35.0
Majority speed (mph)	25.0	25.0	25.0	35.0	35.0	35.0
Maximum speed (mph)	55.0	40.0	30.0	55.0	50.0	35.0
Mean volume	12,409.1	11,892.4	11,675.7	8,174.8	7,883.0	7,207.4
Maximum volume	29,815.1	19,247.0	13,407.9	21,961.3	14,987.4	9,213.8
Link count	356.0	124.0	12.0	207.0	76.0	8.0
Link–node ratio	1.5	1.6	2.2	1.2	1.3	1.8
Density of ≥3-way intersections	0.8	0.8	1.0	0.6	0.6	0.7
Census block density (no. of census blocks per neighborhood)	132.0	50.0	8.0	68.0	26.0	5.0

TABLE 2 Agreement between perceived and objective measures of the built environment by study site

	Agreement between perception of the built environment and the objectively measured environment			Agreement between perception of the built environment as a barrier to physical activity and the objectively measured built environment		
	Kappa statistics			Kappa statistics		
	one mile	Half mile	Eighth mile	one mile	Half mile	Eighth mile
Jackson, MS (n=599)						
High-speed traffic[a]	0.00 (−0.08, 0.08)	0.02 (−0.06, 0.10)	0.14 (0.06, 0.22)	0.02 (−0.06, 0.10)	0.00 (−0.08, 0.07)	0.10 (0.02, 0.17)
Heavy traffic[b]	0.02 (−0.06, 0.09)	−0.01 (−0.09, 0.07)	−0.01 (−0.08, 0.07)	0.03 (−0.04, 0.11)	0.05 (−0.03, 0.12)	0.04 (−0.04, 0.11)
Street connectivity[c]	NA	NA	NA	0.14 (0.07, 0.21)	0.15 (0.07, 0.22)	0.06 (−0.01, 0.14)
Forsyth County, NC (n=671)						
High-speed traffic[a]	0.02 (−0.05, 0.10)	0.04 (−0.04, 0.11)	−0.03 (−0.10, 0.05)	0.06 (−0.02, 0.13)	0.07 (−0.01, 0.14)	0.05 (−0.02, 0.12)
Heavy traffic[b]	0.08 (0.00, 0.15)	0.09 (0.02, 0.16)	0.11 (0.04, 0.19)	0.03 (−0.04, 0.10)	0.00 (−0.07, 0.07)	0.03 (−0.04, 0.10)
Street connectivity[c]	NA	NA	NA	0.32 (0.25, 0.39)	0.30 (0.23, 0.37)	0.19 (0.11, 0.26)

[a]Perception of high-speed traffic compared to the objectively measured summary variable for speed that resulted from exploratory factor analyses.
[b]Perception of heavy traffic compared to the objectively measured summary variable for volume that resulted from exploratory factor analyses.
[c]Perception of street connectivity compared to the objectively measured summary variable for street characteristics from exploratory factor analyses.

measures indicate that Jackson MS has greater connectivity than Forsyth County, NC, suggesting that Jackson, MS consists of a more traditional neighborhood design and Forsyth County, NC exhibits characteristics more indicative of urban sprawl. Because of the differences in values of the objective measures between the two study areas, we stratified analyses by study area.

Agreement

The objective summary scores for speed and volume were compared to (1) perceptions of high-speed vehicles and heavy traffic being a problem in one's neighborhood and (2) whether high-speed vehicles and heavy traffic were barriers to physical activity for the three different neighborhood sizes in each study site (Table 2). Agreement between the objectively measured environment and perceptions of the environment was quite poor for both study sites. Kappa statistics were also calculated to estimate agreement between perceptions of walkable destinations and the street connectivity/density summary score (Table 2). Agreement between these two variables was poor for Jackson, MS and poor to fair for Forsyth County NC.

Agreement between the objective variables and both of the perceived measures was also calculated for each type of physical activity stratified by activity level to determine if agreement differed between active and inactive individuals. The agreement between objective and perceived measures for categories of leisure activity, outdoor leisure activity, and walking (meets recommendations, insufficiently active, or inactive) or transportation activity (any vs. none) were similar in magnitude to those shown for the entire sample in Table 2 (data not shown). The perception of crashes was not assessed on the survey; therefore, agreement could not be calculated.

Association of Perceptions of the Built Environment with Physical Activity

Approximately one third to two thirds of the respondents agreed or strongly agreed that high-speed traffic, heavy traffic, lack of crosswalks, or lack of sidewalks were a problem in their neighborhood (Table 3). Respondents in Forsyth, NC were more than twice as likely to report no walkable destinations than respondents in Jackson MS (44.7 vs 20.6%, respectively), further substantiating the differences in urban design of the two study areas. Separate models were run for each of the four physical activity outcomes with these five variables collectively entered as independent predictors of physical activity and stratified by study site (Table 3). In Jackson, MS, perception of lack of crosswalks not being a problem in the neighborhood was associated with being insufficiently active compared to inactive for leisure activity and outdoor leisure activity. Perception of the lack of crosswalks not being a problem in the neighborhood was also associated with a decreased odds of engaging in any transportation activity in Jackson, MS and in Forsyth County, NC. In Forsyth County, NC, perceiving the presence of walkable destinations was associated with meeting recommendations for walking for any purpose and any transportation activity. Perception of high-speed traffic, heavy traffic, and lack of sidewalks as problems in one's neighborhood were not associated with any of the physical activity outcomes in either study site.

A smaller percentage of respondents reported that high-speed cars, heavy traffic, lack of crosswalks, or lack of sidewalks in their neighborhood were barriers to physical activity (Table 4). To evaluate the relationship between these perceived

TABLE 3 Weighted prevalence and adjusted odds ratios with 95% confidence intervals for perception of the built environment for all physical activity outcomes, stratified by study area

Main exposure: perceptions of the built environment	Weighted prevalence (n)	Leisure time physical activity		Outdoor leisure time physical activity		Walking for any purpose		Transportation activity
		Meets rec. vs. inactive	Insufficient vs. inactive	Meets Rec. vs. inactive	Insufficient vs. inactive	Meets rec. vs. inactive	Insufficient vs. inactive	Any activity vs. no activity
Model 1: Jackson, MS (n=599)								
High-speed traffic is not a problem	55.5 (327)	0.8 (0.5, 1.3)	0.9 (0.6, 1.4)	0.7 (0.4, 1.2)	0.7 (0.5, 1.1)	1.3 (0.8, 2.3)	0.8 (0.5, 1.4)	0.9 (0.6, 1.3)
High-speed traffic is a problem	44.5 (272)	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Heavy traffic is not a problem	63.4 (379)	1.2 (0.7, 2.1)	0.8 (0.5, 1.3)	1.6 (0.9, 2.9)	1.0 (0.6, 1.5)	0.7 (0.4, 1.3)	0.8 (0.4, 1.3)	1.0 (0.7, 1.6)
Heavy traffic is a problem	36.6 (219)	1.0	1.0	1.0	1.0	1.0	1.0	1.0
There are walkable destinations	79.4 (459)	1.1 (0.6, 1.8)	1.3 (0.8, 2.0)	1.3 (0.7, 2.3)	1.1 (0.7, 1.7)	1.1 (0.6, 1.9)	1.2 (0.7, 2.1)	1.0 (0.6, 1.5)
There are no walkable destinations	20.6 (136)	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Lack of crosswalks is not a problem	68.0 (401)	1.1 (0.7, 1.8)	1.7 (1.1, 2.6)*	1.0 (0.6, 1.8)	1.4 (1.0, 2.2)*	1.0 (0.6, 1.7)	1.1 (0.6, 1.8)	0.7 (0.5, 1.0)*
Lack of crosswalks is a problem	32.0 (195)	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Lack of sidewalks is not a problem	43.7 (260)	1.2 (0.7, 1.9)	0.7 (0.5, 1.1)	1.4 (0.8, 2.3)	0.8 (0.5, 1.2)	1.0 (0.6, 1.7)	1.0 (0.6, 1.6)	1.1 (0.7, 1.6)
Lack of sidewalks is a problem	56.3 (330)	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Model 2: Forsyth County, NC (n=671)								
High-speed traffic is not a problem	60.4 (402)	1.1 (0.6, 1.8)	0.7 (0.4, 1.1)	1.0 (0.6, 1.8)	1.0 (0.7, 1.5)	0.8 (0.4, 1.3)	0.6 (0.4, 1.1)	0.8 (0.5, 1.2)
High-speed traffic is a problem	40.6 (269)	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Heavy traffic is not a problem	67.0 (455)	1.1 (0.7, 1.9)	1.5 (0.9, 2.4)	1.1 (0.6, 2.0)	1.1 (0.7, 1.7)	0.8 (0.4, 1.4)	1.0 (0.5, 1.7)	1.5 (0.9, 2.3)
Heavy traffic is a problem	32.0 (214)	1.0	1.0	1.0	1.0	1.0	1.0	1.0
There are walkable destinations	55.3 (343)	1.4 (0.9, 2.1)	1.1 (0.7, 1.6)	1.3 (0.8, 2.2)	1.0 (0.7, 1.5)	1.7 (1.1, 2.8)*	1.2 (0.8, 1.9)	1.4 (1.0, 2.1)*
There are no walkable destinations	44.7 (326)	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Lack of crosswalks is not a problem	71.8 (476)	1.0 (0.6, 1.6)	0.9 (0.6, 1.5)	0.9 (0.5, 1.7)	0.9 (0.6, 1.3)	1.2 (0.7, 2.0)	1.3 (0.8, 2.2)	0.7 (0.5, 1.0)*
Lack of crosswalks is a problem	28.2 (190)	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Lack of sidewalks is not a problem	51.7 (330)	1.1 (0.7, 1.8)	1.1 (0.8, 1.7)	1.1 (0.7, 1.8)	1.2 (0.9, 1.7)	1.0 (0.6, 1.6)	0.8 (0.5, 1.3)	1.0 (0.7, 1.4)
Lack of sidewalks is a problem	48.3 (326)	1.0	1.0	1.0	1.0	1.0	1.0	1.0

All models are adjusted for age, gender, and race/ethnicity. Forsyth County models are also adjusted for urbanicity.
*denotes $p<0.05$

TABLE 4 Weighted prevalence and adjusted odds ratios with 95% confidence intervals for perception of the built environment as a barrier to physical activity for all physical activity outcomes, stratified by study area

Main exposure: perception of the built environment as barriers to physical activity	Weighted prevalence (*n*)	Leisure time physical activity		Outdoor leisure time physical activity		Walking for any purpose		Transportation activity
		Meets rec. vs. Inactive	Insufficient vs. inactive	Meets rec. vs. inactive	Insufficient vs. inactive	Meets rec. vs. inactive	Insufficient vs. inactive	Any activity vs. no activity
Model 3: Jackson, MS								
High-speed traffic is not a barrier	64.9 (386)	0.8 (0.4, 1.4)	1.0 (0.6, 1.6)	0.6 (0.3, 1.1)	0.8 (0.5, 1.3)	0.9 (0.5, 1.7)	0.8 (0.4, 1.4)	1.3 (0.8, 2.0)
High-speed traffic is a barrier	35.1 (211)	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Heavy traffic is not a barrier	70.7 (419)	1.0 (0.5, 1.9)	0.8 (0.5, 1.4)	1.7 (0.8, 3.4)	1.0 (0.6, 1.6)	1.0 (0.5, 1.9)	1.0 (0.5, 1.8)	0.9 (0.6, 1.5)
Heavy traffic is a barrier	29.3 (180)	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Lack of crosswalks is not a barrier	76.7 (460)	1.8 (1.0, 3.2)*	2.3 (1.4, 3.9)*	1.6 (0.8, 3.1)	2.0 (1.3, 3.3)*	1.4 (0.7, 2.6)	1.3 (0.7, 2.3)	0.7 (0.4, 1.1)
Lack of crosswalks is a barrier	23.3 (136)	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Lack of sidewalks is not a barrier	52.5 (307)	1.1 (0.6, 1.8)	0.9 (0.6, 1.4)	1.0 (0.6, 1.7)	0.7 (0.5, 1.1)	0.7 (0.4, 1.2)	0.9 (0.5, 1.5)	0.8 (0.5, 1.2)
Lack of sidewalks is a barrier	47.5 (291)	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Model 4: Forsyth County, NC								
High-speed traffic is not a barrier	70.2 (465)	0.9 (0.5, 1.6)	1.0 (0.6, 1.6)	0.9 (0.5, 1.6)	1.3 (0.8, 2.1)	0.7 (0.4, 1.3)	0.7 (0.4, 1.2)	1.0 (0.6, 1.6)
High-speed traffic is a barrier	29.8 (204)	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Heavy traffic is not a barrier	78.0 (513)	1.0 (0.5, 1.9)	1.1 (0.6, 2.0)	1.0 (0.5, 2.1)	0.9 (0.6, 1.6)	1.0 (0.5, 2.0)	1.4 (0.7, 2.8)	0.8 (0.5, 1.3)
Heavy traffic is a barrier	22.0 (155)	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Lack of crosswalks is not a barrier	78.3 (517)	0.8 (0.4, 1.4)	0.8 (0.5, 1.3)	0.6 (0.3, 1.2)	0.6 (0.4, 1.0)*	0.9 (0.5, 1.8)	0.8 (0.4, 1.5)	0.7 (0.4, 1.1)
Lack of crosswalks is a barrier	21.7 (153)	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Lack of sidewalks is not a barrier	61.9 (394)	1.3 (0.8, 2.1)	1.3 (0.8, 2.0)	1.4 (0.8, 2.5)	1.4 (1.0, 2.1)*	1.4 (0.8, 2.4)	1.0 (0.6, 1.6)	1.3 (0.9, 1.9)
Lack of sidewalks is a barrier	38.1 (275)	1.0	1.0	1.0	1.0	1.0	1.0	1.0

All models are adjusted for age, gender, and race/ethnicity. Forsyth County models are also adjusted for urbanicity.
*denotes $p<0.05$

barriers to physical activity and self-reported physical activity, separate regression models were run for each of the four physical activity outcomes with these four variables collectively entered as independent predictors of physical activity, and models were stratified by study site (Table 4). In Jackson, MS, perceiving the absence of crosswalks as not being a barrier to physical activity increased the odds of being active during leisure activity and outdoor leisure activity. However, in Forsyth County, NC, perceiving the absence of crosswalks as not being a barrier to physical activity was associated with a decreased odds of being active, particularly for being insufficiently active vs. inactive during outdoor leisure activity. Also, in Forsyth County, NC, perceiving the absence of sidewalks as not being a barrier to physical activity was associated with an increased odds of activity, particularly for being insufficiently active vs. inactive during outdoor leisure activity.

Association of the Objectively Measured Built Environment with Physical Activity

Odds ratios and 95% confidence limits for the objectively measured built environment factors at one-mile, half-mile, and eighth-mile radius around each participant's home address are reported in Table 5 separately for each study area. The speed, volume, and street connectivity/density summary scores were treated as the independent variables for both study areas. In addition, the accident variable was treated as an independent variable in the Forsyth County, NC study area.

In Jackson, MS those whose one-mile neighborhoods had low-traffic volumes were less likely to meet recommendations or to be insufficiently active than to be inactive during leisure activity, outdoor leisure activity, or walking for any purpose, with significant associations for being insufficiently active compared to inactive during leisure activity and walking for any purpose. No associations were seen between objectively measured speed and street characteristics for any of the outcomes in any of the three neighborhood sizes in Jackson.

Results for the Forsyth County, NC study area indicate that those living in areas of low-traffic speed were more likely to meet recommendations for leisure activity than to be inactive for all three buffer sizes, compared to those living in areas of high-traffic speed. Those living in areas of low-traffic volume were also more likely to be insufficiently active during leisure physical activity and outdoor leisure activity than to be inactive and to engage in any transportation activity; however, these associations were only significant in the eighth mile buffer. In addition, those whose one-mile and half-mile neighborhoods had high connectivity were more likely to meet recommendations or to be insufficiently active during outdoor leisure activity than to be inactive, with a statistically significant association seen in the half-mile neighborhoods. Conversely, for the eighth-mile buffer, those neighborhoods with high connectivity were less likely to meet recommendations or to be insufficiently active than to be inactive during leisure activity and for walking for any purpose.

In the Forsyth County, NC study area, those who lived in areas were there was a low occurrence of crashes were more likely to meet recommendations for leisure physical activity for the one mile and half mile neighborhoods, although this was only significant in the one-mile buffer. Conversely, those who live in areas of low crashes were less likely to engage in any transportation activity than those who live in areas with a high occurrence of crashes for both the one-mile and half-mile neighborhoods.

TABLE 5 Weighted prevalence and adjusted odds ratios with 95% confidence intervals for the objectively measured built environment with all physical activity outcomes for the one-mile, half-mile, and eighth-mile neighborhoods surrounding respondents home addresses

Main exposure	Weighted prevalence (*n*)	Leisure time physical activity		Outdoor leisure time physical activity		Walking for any purpose		Transportation activity
		Meets rec. vs. inactive	Insufficient vs. inactive	Meets rec. vs. inactive	Insufficient vs. inactive	Meets rec. vs. inactive	Insufficient vs. inactive	Any activity vs. no activity
Jackson, MS								
Model 5: one mile								
High speed	42.6 (245)	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Low speed	57.4 (345)	1.3 (0.7, 2.4)	1.0 (0.6, 1.7)	1.3 (0.7, 2.4)	0.9 (0.6, 1.5)	1.2 (0.2, 2.3)	1.3 (0.7, 2.4)	1.1 (0.7, 1.8)
High volume	44.9 (260)	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Low volume	55.1 (339)	0.6 (0.3, 1.1)	0.5 (0.3, 0.9)*	0.7 (0.3, 1.3)	0.7 (5, 1.2)	0.6 (0.3, 1.2)	0.5 (0.3, 1.0)*	1.1 (0.6, 1.7)
Low street connectivity	43.9 (268)	1.0	1.0	1.0	1.0	1.0	1.0	1.0
High street connectivity	56.1 (331)	1.0 (0.6, 1.6)	0.8 (0.5, 1.2)	1.0 (0.6, 1.7)	0.8 (0.5, 1.1)	0.9 (0.6, 1.5)	0.9 (0.6, 1.7)	1.4 (0.9, 2.0)
Model 6: half mile								
High speed	47.3 (289)	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Low speed	52.7 (310)	1.1 (0.7, 1.8)	0.8 (0.5, 1.2)	1.3 (0.8, 2.1)	0.8 (0.5, 1.1)	1.0 (0.6, 1.7)	0.8 (0.5, 1.3)	0.9 (0.6, 1.3)
High volume	42.4 (248)	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Low volume	57.6 (351)	0.9 (0.5, 1.4)	1.0 (0.6, 1.5)	0.8 (0.5, 1.3)	1.2 (0.8, 1.9)	1.1 (0.6, 1.8)	1.1 (0.7, 1.8)	1.2 (0.8, 1.8)
Low street connectivity	43.9 (271)	1.0	1.0	1.0	1.0	1.0	1.0	1.0
High street connectivity	56.1 (328)	0.9 (0.6, 1.5)	1.1 (0.8, 1.7)	0.8 (0.5, 1.3)	1.1 (0.8, 1.6)	1.1 (0.7, 1.8)	1.4 (0.9, 2.2)	1.3 (0.9, 1.9)
Model 7: eighth mile								
High speed	49.4 (296)	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Low speed	50.6 (303)	0.9 (0.6, 1.5)	1.2 (0.8, 1.8)	0.8 (0.5, 1.3)	1.0 (0.7, 1.4)	0.8 (0.5, 1.3)	0.9 (0.6, 1.4)	0.8 (0.6, 1.2)
High volume	47.6 (278)	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Low volume	52.4 (321)	0.7 (0.5, 1.1)	0.7 (0.5, 1.1)	0.7 (0.4, 1.2)	1.1 (0.8, 1.6)	1.0 (0.6, 1.6)	0.8 (0.6, 1.6)	1.1 (0.7, 1.6)
Low street connectivity	37.5 (230)	1.0	1.0	1.0	1.0	1.0	1.0	1.0
High street connectivity	62.5 (358)	0.9 (0.6, 1.5)	0.9 (0.6, 1.3)	1.0 (0.6, 1.7)	0.9 (0.6, 1.4)	0.9 (0.5, 1.4)	0.7 (0.5, 1.2)	1.2 (0.8, 1.8)

Forsyth County, NC								
Model 8: one mile								
High speed	42.5 (288)	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Low speed	57.5 (383)	1.7 (1.0, 2.7)*	1.2 (0.8, 1.8)	1.0 (0.6, 1.7)	1.0 (0.7, 1.5)	1.0 (0.6, 1.6)	0.9 (0.5, 1.4)	1.2 (0.8, 1.7)
High volume	44.6 (275)	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Low volume	55.4 (396)	0.9 (0.5, 1.5)	1.3 (0.8, 2.1)	1.6 (0.9, 2.8)	1.4 (0.9, 2.2)	1.2 (0.7, 2.0)	1.0 (0.6, 1.7)	1.4 (0.9, 2.1)
Low street connectivity	44.4 (316)	1.0	1.0	1.0	1.0	1.0	1.0	1.0
High street connectivity	55.6 (355)	1.0 (0.6, 1.9)	1.1 (0.6, 1.8)	1.8 (0.9, 3.6)	1.3 (0.8, 2.1)	0.9 (0.5, 1.6)	1.1 (0.6, 2.0)	1.1 (0.7, 1.8)
High crash rate	24.1 (145)	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Low crash rate	75.9 (526)	1.9 (1.0, 3.4)*	1.3 (0.8, 2.1)	1.1 (0.6, 2.0)	1.4 (0.9, 2.3)	0.8 (0.4, 1.6)	1.0 (0.5, 1.8)	0.6 (0.4, 1.0)*
Model 9: half mile								
High speed	33.6 (232)	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Low speed	66.4 (439)	1.6 (1.0, 2.6)*	1.1 (0.7, 1.6)	1.2 (0.7, 2.0)	1.0 (0.7, 1.4)	0.9 (0.5, 1.4)	1.0 (0.6, 1.6)	1.0 (0.7, 1.5)
High volume	48.3 (297)	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Low volume	51.7 (374)	0.9 (0.5, 1.4)	1.3 (0.8, 1.9)	1.2 (0.7, 2.0)	1.3 (0.9, 1.9)	1.2 (0.7, 2.0)	1.0 (0.6, 1.6)	1.4 (0.9, 2.0)
Low street connectivity	38.9 (281)	1.0	1.0	1.0	1.0	1.0	1.0	1.0
High street connectivity	61.1 (390)	1.2 (0.7, 2.0)	1.1 (0.7, 1.7)	1.7 (0.9, 3.0)	1.5 (1.0, 2.2)*	0.9 (0.5, 1.6)	0.8 (0.5, 1.4)	1.0 (0.7, 1.6)
High crash rate	23.7 (154)	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Low crash rate	76.3 (517)	1.6 (0.9, 2.8)	1.1 (0.7, 1.8)	1.4 (0.7, 2.6)	1.3 (0.8, 2.0)	1.0 (0.5, 1.9)	0.6 (0.3, 1.1)	0.6 (0.4, 0.9)*
Model 10: eighth mile								
High speed	47.2 (333)	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Low speed	52.8 (338)	2.1 (1.3, 3.4)*	1.1 (0.7,1.7)	1.6 (0.9, 2.8)	1.0 (0.7, 1.5)	1.1 (0.6, 1.7)	1.1 (0.6, 1.7)	1.1 (0.7, 1.6)
High volume	48.6 (300)	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Low volume	51.4 (371)	1.2 (0.8, 2.0)	1.6 (1.0, 2.3)*	1.2 (0.7, 2.0)	1.4 (1.0, 2.0)*	1.1 (0.7, 1.8)	1.0 (0.6, 1.6)	1.4 (1.0, 2.1)*
Low street connectivity	40.8 (278)	1.0	1.0	1.0	1.0	1.0	1.0	1.0
High street connectivity	59.2 (376)	0.7 (0.4, 1.0)*	0.7 (0.5, 1.0)*	0.9 (0.6, 1.6)	0.9 (0.7, 1.3)	0.7 (0.4, 1.2)	0.7 (0.4, 1.0)*	1.0 (0.7, 1.5)
High crash rate	17.3 (107)	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Low crash rate	82.8 (564)	0.7 (0.4, 1.2)	0.9 (0.5, 1.6)	0.6 (0.3, 1.1)	1.1 (0.7, 1.9)	1.1 (0.6, 2.2)	0.9 (0.5, 1.7)	0.7 (0.5, 1.2)

All models are adjusted for age, gender, and race/ethnicity and study area. Forsyth County, NC model is also adjusted for urbanicity. Further adjustment for marital status, work activity, number of children in the household, education, household income, availability of motor vehicle for personal use, and general health or disability that limits physical activity did not change the results substantially.

*denotes $p<0.05$

Combined Associations of the Perceived and Objectively Measured Built Environment with Physical Activity

Odds ratios and 95% confidence limits for the combined associations of perceived and objectively measured built environment for Jackson, MS and Forsyth County, NC were also evaluated (data not shown). The associations seen in the individual models evaluating the relationship between perceived attributes of the built environment as problems in the neighborhood, perceived attributes as barriers to physical activity, and objective measures of the built environment were also seen in the combined models, with similar magnitudes of association, for all three buffer sizes in both study areas. Given the lack of agreement between objective and perceived measures of the built environment, observing little or no change in the point estimates when combining both measures into one model is not surprising.

Model Fit

Model fit was assessed using likelihood ratio tests comparing models with objective measures and models with perceived measures to models with both objective and perceived measures combined. In general, the models with combined measures were a better fit than the models with objective measures only and the models with perceived measures only; however, the differences were not statistically significant.

DISCUSSION

We found little agreement between perceptions of the built environment and the objectively measured built environment in either study area. Agreement between perceptions of high-speed vehicles and heavy traffic with objectively measured speed and volume, respectively, was negligible in this study. These findings are consistent with those of Kirtland et al. [27] who reported a kappa of 0.02 for the agreement between perceived traffic volume and objectively measured traffic counts in a half-mile radius around participant's homes. The poor agreement seen between these perceived and objective measures may indicate that they are assessing different dimensions of one's physical environment, yet it may also be because of the manner in which the environment was objectively measured in the present study: Posted speed limits were used in place of actual vehicular speeds and traffic volume for the entire study area was interpolated from traffic monitors placed on select roads. Another possibility is that one's latest experience with traffic may be more influential than the average traffic in their neighborhood over time, which may cause us to observe low agreement between perceived and observed measures. Our objective measures of street connectivity illustrated some agreement with respondents' perception of having places to walk to instead of driving; however, the agreement was still poor. It should be noted that the objective measure of street connectivity/density in this study may not have been a perfect match for the perceived question on walkable destinations because our objective measure did not take into account features such as open spaces, water, actual destinations, and land use mix. For example, it is possible that an area is well-connected but still purely residential with few businesses within walking distance.

We found that perceptions of speed and volume being a problem in the neighborhood were not associated with any of the physical activity outcomes. This is in agreement with most studies assessing perceived traffic or safety from traffic: Perception of traffic was not associated with leisure physical activity in two studies of U.S. older and middle-aged women overall, by ethnicity or by place of residence;[24,25] perception of heavy traffic was not associated with walking in a random sample of U.S. adults;[23] and feeling safe from traffic was not associated with transportation or recreational activity in urban adults.[56] According to one author, the lack of association may be because of both active and inactive persons feeling unsafe around high speed and heavy traffic;[56] however, we found that approximately the same percentage of respondents in each activity level, for each outcome, reported feeling that high-speed traffic and heavy traffic were barriers to physical activity in areas of both low- and high-speed and volume (data not shown). In addition, we did not find any associations between perception of speed and volume being barriers to physical activity and any of the physical activity outcomes in regression analyses.

Perception of having places to walk to was associated with higher levels of physical activity, particularly walking for any purpose and transportation activity, in Forsyth County, NC. This is in agreement with other studies that evaluated the association of one's perception of being able to walk to destinations with physical activity level. A convenience score composed of responses to questions on whether shops, parks, or beaches were within walking distance and whether a bike path was accessible was associated with walking for exercise in one Australian study.[57] Higher pedometer readings, indicating more walking, was associated with self-report of living within walking distance of parks, trails, or stores in older white women in Pittsburgh, PA,[58] with a positive trend between the sum of destinations within walking distance of one's home and pedometer readings. Most recently, the count of nonresidential destinations was associated with walking and bicycling for transportation purposes in a study of urban adults.[56]

In Jackson, MS, the perception of lack of crosswalks not being a problem in the neighborhood was associated with increased leisure and outdoor leisure activity. In addition, the perception of lack of crosswalks not being a barrier to physical activity was associated with increased leisure and outdoor leisure activity. However, in Forsyth County, NC, the perception of lack of crosswalks not being a problem in the neighborhood was associated with decreased transportation activity, and the perception of lack of crosswalks as a barrier to physical activity was associated with decreased activity in general, with statistically significant associations seen for outdoor activity. These results may seem contradictory at first, but when the overall characteristics of the two study sites are taken into consideration, the results may make better sense. Jackson, MS is much more densely populated than Forsyth County, NC and has an overall greater volume of traffic and higher street connectivity (Table 1). Having crosswalks in an area with greater traffic volume and good street connectivity may play a larger role in determining physical activity levels than in a less populated, lower traffic volume area such as Forsyth County.

Conflicting results for objectively measured traffic volume were found in our study. In Jackson, MS, having objectively measured low-traffic volume around one's home was associated with less leisure activity in the one mile buffer. In Forsyth County, NC, having objectively measured low-traffic volume around one's home was associated with more transportation and leisure activity in the eighth mile buffer. However, it should be noted that high-traffic volume may not always indicate a poor environment for physical activity. In fact, high-traffic volume combined with low-traffic speeds *may* be indicative of a vibrant downtown area that is highly conducive to activity. It is only when high-traffic volume is combined with high-traffic speeds that being physically active outdoors may pose a problem. Thus, the differences in association between traffic volume and physical activity between the two study areas may be rooted in the overall neighborhood design of the two areas.

There were several other associations between objective measures and physical activity in Forsyth County, NC: Respondents living in low-speed areas were more likely to meet recommendations for physical activity, and respondents in neighborhoods with high street connectivity were more likely to be active during outdoor leisure for one-mile and half-mile buffers. These results confirm our hypotheses that individuals living in areas with low speeds and high street connectivity are more physically active.

In Forsyth County, NC, a lower crash rate was associated with an increased odds of meeting recommendations for leisure activity, but a decrease in odds of engaging in any transportation activity. This may be because persons performing leisure activity have more of a choice of where they will be active. However, if one is walking or bicycling for transportation purposes then one is bound by their home destination and the target of their destination, thereby limiting the number of streets for efficient travel. These transportation routes are likely to be well-traveled by others, both using motorized and nonmotorized transportation, thus increasing the likelihood of an accident. In addition, our calculation of crash exposure is not perfect. Ideally, we would like to have used pedestrian and bicycle traffic to calculate crash exposure; however, this was not feasible in our study. Instead, we used an imperfect alternative, population in block group, which may reflect on the transportation variable because an area can have high a pedestrian–bicycle crash rate solely because there is little or no population in that area. For example, a business district, which may attract many pedestrians and cyclists traveling to work, would have a high crash rate by our measure because the population density is low (i.e., there are no residences).

Using log likelihood statistics we found that, generally, models with both objective and perceived measures were a better fit than models with objective measures or models with perceived measures alone. Given that our results also imply that for certain aspects of the built environment, perceived and objective measures were independently associated with physical activity, we feel that evaluating both objective and perceived measures of the built environment are necessary when examining the relationship between the built environment and physical activity.

STRENGTHS AND LIMITATIONS

Several limitations of this study should be noted. First, this research relied on self-reported physical activity obtained through a telephone interview, rather than objectively measured physical activity. A further limitation of this study is the inability to control for variables that may affect the choice an individual makes about where to live. If individuals choose to live somewhere because of the characteristics of those areas, (e.g., an individual moves to a neighborhood because it is a safer neighborhood to walk or because it has a pattern of streets amenable to walking) it becomes difficult to separate the direction of causality between individual values, the environment, and that individual's physical activity behavior. Thus, any interpretation of the data will need to take into account the cross-sectional nature of the study. In addition, the low response rate for the study also limits the generalizability of our results.

Although this is one of the first studies to use GIS to objectively measure aspects of the built environment hypothesized to affect physical activity, such as speed, volume, and street connectivity, these measures may not adequately reflect all features of the built environment that influence physical activity levels. For example, several measures, such as location of crosswalks and presence of sidewalks, likely play a great role in whether an individual is active in their neighborhood, yet we were unable to collect information on such aspects of the environment. Also, because of the large number of objective variables being measured and the data distribution within these variables, we chose to dichotomize the objective built environment measures at the median when creating the summary scores derived from factor analyses. By doing so there may have been a loss in the amount of variation in the data, as the median may not represent a meaningful cut-point for all of the objective measures of the built environment examined, thus explaining some of the lack of agreement and associations observed in this study. Alternative cut-points should be examined in future studies with greater statistical power. Furthermore, the measures we did collect may not accurately reflect the true environment; for example, posted speed limits may not be an accurate proxy for actual speed. Lastly, we did not collect information on land development attributes, such as land use mix and such measures that were shown to be relevant, especially for transportation activity.[22]

One strength of this study is that we also examine where physical activity occurs. Recent research has suggested that where physical activity occurs is important to understand the relationship between the built environment and physical activity. It also allows for identifying the potential for individuals to choose where they can be active: in their home, in the proximity of home or work, or elsewhere. In this study participants were asked if they have places to be physically active (indoor, outdoor, both, or neither) in their neighborhood and the majority of the respondents (83%) indicated that they had places outdoors to be physically active. We also created an outcome variable that included only those leisure physical activities likely to be performed outdoors near the home (outcome=outdoor leisure time physical activity) and the results between this outcome and the leisure time physical activity outcome were very similar. Thus, although the possibility of being physically active outdoors away from home remains, our results suggest that activity close to home closely approximates overall leisure physical activity.

CONCLUSION

Our evaluation of the built environment addresses some of the common limitations of past research in the fields of public health, transportation, and urban and city planning. We were able to evaluate the built environment in two geographic locations: Forsyth County, NC and Jackson City, MS.

Results indicate that any potential interventions aimed to increase physical activity at the neighborhood level will need to be tailored to best suit individual communities. Communities that are already conducive to physical activity, from a built environment view, may benefit from a more in depth evaluation to discover other aspects of the neighborhood environment that may be contributing to low physical activity levels. On the other hand, communities with built environment designs that are not conducive to physical activity may benefit more, at least initially, from policy interventions aimed at improving the environment. However, more research is needed to sort out the causal mechanism between the built environment and physical activity, as well as on how and why individual's perceptions are formed and influenced, before any such interventions are undertaken.

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REFERENCES

1. U.S. Department of Health and Human Services Centers for Disease Control and Prevention National Center for Chronic Disease Prevention and Health Promotion. *Physical activity and health: a report of the Surgeon General*. Atlanta, GA: U.S. Department of Health and Human Services Centers for Disease Control and Prevention National Center for Chronic Disease Prevention and Health Promotion; 1996.
2. Pate RR, Pratt M, Blair SN, et al. Physical activity and public health. A recommendation from the Centers for Disease Control and Prevention and the American College of Sports Medicine. *JAMA*. 1995;273(5):402–407.
3. Breslow L. Social ecological strategies for promoting healthy lifestyles. *Am J Health Promot*. 1996;10(4):253–257.
4. Hill JO, Goldberg JP, Pate RR, Peters JC. Proceedings of the partnership to promote healthy eating and active living summit. *Nutr Rev.* March 2001;59(3):S4–S6.
5. McLeroy KR, Bibeau D, Stecker A, Glanz K. An ecologic perspective on health promotion programs. *Health Educ Q*. 1988;15(4):351–377.
6. von Korff M, Koepsell T, Curry S, Diehr P. Multi-level analysis in epidemiologic research on health behaviors and outcomes. *Am J Epidemiol*. 1992;135(10):1077–1082.
7. Green L, McAlister A. Macro-intervention to support health behavior: some theoretical perspectives and practical reflections. *Health Educ*. 1984;11:322–339.
8. Green L, Richard L. The need to combine health education and health promotion: the case of cardiovascular disease prevention. *Promot Educ*. 1993;1:11–17.
9. Schmid TL, Pratt M, Howze E. Policy as intervention: environmental and policy approaches to the prevention of cardiovascular disease. *Am J Public Health*. 1995; 85:1207–1211.
10. Handy SL, Boarnet MG, Ewing R, Killingsworth R. How the built environment affects physical activity: views from urban planning. *Am J Prev Med*. 2002;23(2S):64–73.
11. Frumkin H. Urban sprawl and public health. *Public Health Rep*. May–June 2002; 117:201–217.
12. Saelens BE, Sallis JF, Frank LD. Environmental correlates of walking and cycling: findings from the transportation, urban design, and planning literatures. *Ann Behav Med*. 2003;25(2):80–91.
13. 1000 Friends of Oregon. *The pedestrian environment (Vol 4a)*. Portland, OR: Parsons Brinkerhoff Quade & Douglas Inc.; 1993.
14. Greenwald M, Boarnet M. The built environment as a determinant of walking behavior: analyzing non-work pedestrian travel in Portland, Oregon. *Transp Res Rec*. 2002;1780:33–42.
15. Cervero R, Kockelman K. Travel demand and the 3Ds: density, diversity, and design. *Transp Res Part D Trans Environ*. 1997;2(3):199–219.
16. Cervero R, Duncan M. Walking, bicycling and urban landscapes: evidence from the San Francisco Bay Area. *Am J Public Health*. 2003;93(9):1478–1483.
17. Krizek KJ. Residential relocation and changes in urban travel: does neighborhood-scale urban form matter? *J Am Plan Assoc*. 2003;69(3):265–282.
18. Song Y. Comparing urban growth in U.S. metropolitan areas: a spatial analysis of urban form. *Int Reg Sci Rev.* 2005;28(2):239–265.
19. Song Y, Knaap G-J. Measuring urban form: Is Portland winning the war on sprawl. *J Am Plan Assoc*. 2004;70(2):210–225.

20. Frank LD, Schmid TL, Sallis JF, Chapman J, Saelens BE. Linking objectively measured physical activity with objectively measured urban form: Findings from SMARTRAQ. *Am J Prev Med*. 2005;28(2 Suppl 2):117–125.
21. Ross C, Dunning A. *Land Use Transportation Interaction: An Examination of the 1995 NPTS Data*. Atlanta, GA: U.S. Department of Transportation, Federal Highway Administration; 1997.
22. Frank L, Pivo G. Impacts of mixed use and density on utilization of three modes of travel: Single-occupant vehicle, transit, and walking. *Transp Res Rec*. 1994;1466:44–52.
23. Eyler AA, Brownson RC, Bacak SJ, Housemann R. The epidemiology of walking for physical activity in the United States. *Med Sci Sport Exerc*. 2003;35(9):1529–1536.
24. King AC, Castro C, Wilcox S, et al. Personal and environmental factors associated with physical inactivity among different racial/ethnic groups of U.S. middle- and older-aged women. *Health Psychol*. 2000;19(4):354–364.
25. Wilcox S, Castro C, King AC, Housemann R, Brownson RC. Determinants of leisure time physical activity in rural compared with urban older and ethnically diverse women in the United States. *J Epidemiol Community Health*. 2000;54(9):667–672.
26. Huston S, Evenson KR, Bors P, Gizlice Z. Neighborhood environment, access to places for physical activity, and leisure time physical activity in a diverse North Carolina population. *Am J Health Promot*. 2003;18(1):58–69.
27. Kirtland KA, Porter DE, Addy CL, et al. Environmental measures of physical activity supports: Perception versus reality. *Am J Prev Med*. 2003;24(4):323–331.
28. Troped PJ, Saunders RP, Pate RR, et al. Associations between self-reported and objective physical environmental factors and use of a community rail-trail. *Prev Med*. 2001;32:191–200.
29. Giles-Corti B, Donovan RJ. The relative influence of individual, social and physical environment determinants of physical activity. *Soc Sci Med*. 2002;54:1793–1812.
30. Giles-Corti B, Donovan RJ. Socioeconomic status differences in recreational physical activity levels and real and perceived access to supportive physical environment. *Prev Med*. 2002;35(6):601–611.
31. Centers for Disease Control and Prevention. *Behavioral Risk Factor Surveillance System User's Guide*. Atlanta, GA: U.S. Department of Health and Human Services, Centers for Disease Control and Prevention; 1998.
32. Andrews LW. *Reading Level Calculator*. Available at: www.linda-andrews.com/readability_tool.htm. Accessed November 2002.
33. Evenson KR, McGinn AP. Test–retest reliability of a questionnaire to assess physical environmental factors pertaining to physical activity. *Int J Behav Nutr Phys Act*. 2005; 2:7–13.
34. Evenson KR, McGinn AP. Test–retest reliability of adult surveillance measures of physical activity and inactivity. *Am J Prev Med*. 2005;28(5):470–478.
35. Pikora T, Giles-Corti B, Bull F, Jamrozik K, Donovan R. Developing a framework for assessment of the environmental determinants of walking and cycling. *Soc Sci Med*. 2003;56:1693–1703.
36. Centers for Disease Control and Prevention. Prevalence of physical activity, including lifestyle activities among adults—United States, 2000–2001. *MMWR Morb Mortal Wkly Rep*. 2003;52(32):764–769.
37. Centers for Disease Control and Prevention. Physical activity trends—United States, 1990–1998. *MMWR Morb Mortal Wkly Rep*. 2001;50(9):166–169.
38. Strath S, Bassett Jr. D, Ham S, Swartz A. Assessment of physical activity by telephone interview versus objective monitoring. *Med Sci Sport Exerc*. 2003;35(Suppl 5):S114.
39. Baecke JAH, Burema J, Frijters JER. A short questionnaire for the measurement of habitual physical activity in epidemiological studies. *Am J Clin Nutr*. 1982;36(5):936–942.
40. North Carolina State Center for Health Statistics. *Behavioral Risk Factor Surveillance System (BRFSS) 2000 Questionnaire*. North Carolina State Center for Health Statistics.

Available at: http://www.schs.state.nc.us/SCHS/brfss/pdf/BRFSSQ00.pdf. Accessed July 2001.
41. Environmental Systems Research Institute Inc. *TigerLine Road Network*. Environmental Systems Research Institute Inc. Available at: www.esri.com. Accessed July 2003.
42. Environmental Systems Research Institute, Inc. *Spatial Analyst Extension for Arcview 3.x* (computer program). Version. Redlands, CA: Environmental Systems Research Institute, Inc.; 1998.
43. Dill J. *Measuring Network Connectivity for Bicycling and Walking*. Washington DC: 83rd annual meeting of the transportation research board; 2004.
44. Tchoukanski I. *Edit Tools Extension for ArcView 3.x.ET Spatial Techniques*. Available at: http://ian-ko.com. Accessed July 2003.
45. Zhou Y. *Count Points in Polygons (countpoints.avx) Extension for ArcView 3.x*. Environmental Systems Research Institute, Inc. Available at: http://arcscripts.esri.com/. Accessed July 2003.
46. Alsleben S. *Points & Polyline Tools V1.2 for ArcView 3.x*. Environmental Systems Research Institute, Inc. Available at: http://arcscripts.esri.com/. Accessed July 2003.
47. Environmental Systems Research Institute Inc. *ArcGIS* (computer program). Version 8.1. Redlands, CA: Environmental Systems Research Institute Inc.; 2000.
48. SAS Institute Inc. *SAS* [computer program]. Version 8.2. Cary, NC: SAS Institute Inc.; 2002.
49. Delaune M. *Xtools Extension for Arcview 3.x*. Environmental Systems Research Institute, Inc. Available at: http://arcscripts.esri.com/. Accessed July 2003.
50. Johnson T. *Calculate Demographics (calculate_demographics.ave) Script for ArcView 3.x*. Environmental Systems Research Institute, Inc. Available at: http://arcscripts.esri.com/. Accessed July 2003.
51. Kaiser H. The application of electronic computers to factor analysis. *Educ Psychol Meas*. 1960;20:141–151.
52. Hatcher L, Stepanski E. *A Step-by-step Approach to Using the SAS System for Univariate and Multivariate Statistics*, 1st edn. Cary, NC: SAS Institute Inc.; 1994.
53. Landis J, Koch G. The measurement of observer agreement for categorical data. *Biometrics*. 1977;33:159–174.
54. Research Triangle Institute. *Sudaan Software for the Statistical Analysis of Correlated Data* (computer program). Version 8.0.2. Research Triangle Park, NC: Research Triangle Institute; 2003.
55. Little RJ, Lewitzky S, Heeringa S, Lepkowski J, Kessler RC. Assessment of weighting methodology for the National Co-morbidity Survey. *Am J Epidemiol*. 1997;146(5):439–449.
56. Hoehner CM, Brennan Ramirez LK, Elliott MB, Handy SL, Brownson RC. Perceived and objective environmental measures and physical activity among urban adults. *Am J Prev Med*. 2005;28(2Suppl 2):105–116.
57. Ball K, Bauman A, Leslie E, Owen N. Perceived environmental aesthetics and convenience and company are associated with walking for exercise among Australian adults. *Prev Med*. 2001;33:434–440.
58. King WC, Brach JS, Belle S, et al. The relationship between convenience of destinations and walking levels in older women. *Am J Health Promot*. 2003;18(1):74–82.