Perceived and Objective Environmental Measures and Physical Activity Among Urban Adults

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Background: Enhancing community environments to support walking and bicycling serves as a promising approach to increase population levels of physical activity. However, few studies have simultaneously assessed perceptions and objectively measured environmental factors and their relative association with transportation or recreational physical activity.

Methods: For this cross-sectional study, high- and low-income study areas were selected among census tracts in St. Louis MO ("low-walkable" city) and Savannah GA ("high-walkable" city). Between February and June 2002, a telephone survey of 1068 adults provided measures of the perceived environment and physical activity behavior. In this timeframe, objective measures were collected through environmental audits of all street segments ($n = 1158$). These measures were summarized using 400-m buffers surrounding each respondent. Neighborhood characteristics included the land use environment, transportation environment, recreational facilities, aesthetics, and social environment. Associations were examined between neighborhood features and transportation- and recreation-based activity.

Results: After adjusting for age, gender, and education, transportation activity was negatively associated with objective measures of sidewalk levelness and perceived and objective neighborhood aesthetics. It was positively associated with perceived and objectively measured number of destinations and public transit, perceived access to bike lanes, and objective counts of active people in the neighborhood. Recreational activity was positively associated with perceived access to recreational facilities and objective measures of attractive features.

Conclusions: These findings indicate that physical activities for transportation or recreational are associated with different perceived and objective environmental characteristics. Modifications to these features may change the physical activity behavior of residents exposed to them.

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Introduction

Increasing population rates of physical activity has become a public health priority in the United States and abroad.[1] The prevalence of diseases and adverse health conditions associated with physical inactivity has escalated in recent years.[2] Despite 2 decades of national objectives to increase physical activity,[1] U.S. trends in leisure-time physical activity have remained unchanged.[3] Increases in the distance people travel to get to destinations and the amount of time people spend in their cars pinpoint specific challenges to increasing population rates of physical activity.[4] These trends suggest the timeliness for examining important influences on the capacity of entire populations to engage in physical activity.[1] Health experts are broadening their conceptualization of physical activity from leisure-time activity to active living, "a lifestyle or way of life that integrates physical activity into daily routines with the goal of accumulating at least 30 minutes of activity each day."[5] In addition, public health researchers and practitioners are turning upstream to social, physical, organizational, and political environments that promote or hinder physical activity behavior.[6,7] Several recent studies have highlighted regional or community environmental characteristics that have demonstrated associations with physical activity, for example less sprawl,[8] greater neighborhood walkability,[9–11] and more access to places for physical activity.[12–14]

This new emphasis on understanding how community environments impact active living has created a need to develop measures of environments and routine activities. The majority of public health studies have

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used self-report surveys to assess people's perceptions of their environments.[15] Urban planning studies of walking and bicycling for transportation, on the other hand, have relied on existing data sources to provide objective environmental measures, often with limited availability or flexibility of the content or scale of measurement.[16,17] Few studies have evaluated the effects of street-level (vs larger area–level) characteristics, policies, or practices occurring in an area of a few square miles that may include quality of sidewalks, safety from traffic, destinations, or physical disorder. In addition, most studies have assessed either leisure- or transportation-related physical activity, but not both.

This study examines the association between transportation and recreational physical activity and characteristics of the immediate neighborhood environment, measured simultaneously through self-report (perceived) and environmental audit (objective) methods[18] in four urban settings.

Methods

Study Design

Data for this cross-sectional study were collected between February and June 2003 in higher- and lower-income areas of St. Louis MO (representing a "low-walkable" city) and Savannah GA (representing a "high-walkable" city). The study areas were selected among census tracts in these two cities based on the following 2000 U.S. Census Bureau data: number of households, percentage of population below poverty in 1999 (lowest and highest decile), and area in square miles. The study areas, comprised of seven census tracts in Savannah and four census tracts in St. Louis, covered 4.5 square miles in total area.

Data Collection

Two primary methods of data collection were implemented in this study: (1) a telephone survey to measure activity levels and perceived environmental measures of neighborhood residents; and (2) neighborhood audits to assess, "objectively," the physical and social environments.

Telephone numbers and addresses of residents in the study areas were purchased from a marketing company. The data were collected using a modification of the Centers for Disease Control and Prevention's Behavior Risk Factor Surveillance System sampling scheme and computer-assisted telephone interviewing techniques.[19,20] Telephone interviews were carried out between February and June 2003 among Savannah ($n=600$) and St. Louis ($n=473$) residents (aged 18 to 96 years) with addresses in the selected census tracts (response rate=45%). Telephone respondents were geocoded onto Census TIGER/line road files. To permit comparison between the survey and audit data, respondents who could not be geocoded ($n=5$) were excluded from the current analyses.

Community audits were conducted during daylight hours from March to May 2003. Using handheld computers, trained auditors collected data on each street segment—the length of the road between consecutive intersections—in the study areas. Location and attribute information for each street segment, as well as other key neighborhood features (e.g., walking trail, park, grocery store, restaurant), were recorded using global positioning system technology. A total of 1158 segments were audited (475 in St. Louis, 683 in Savannah). Further details regarding the audit training and data collection procedures have been described previously.[21]

Instrumentation and Measures

Physical activity behavior. Physical activity behavior was assessed using the long version of the International Physical Activity Questionnaire (IPAQ).[22] The IPAQ assesses physical activity over the past 7 days across four domains: occupation, transportation, house/yard work, and recreation/leisure. The International Consensus Group on Physical Activity Measurement has conducted extensive reliability and validity testing of the IPAQ across 12 countries.[22] For the IPAQ long form, most of the test–retest reliability coefficients were around 0.80. Transportation- and recreation-based physical activities were the main outcomes of interest. Transportation activity consisted of weekly minutes of walking and bicycling for transportation. Recreational activity consisted of weekly minutes of walking for leisure and moderate and vigorous leisure-time activity.

Respondents who reported physical impairments or disabilities that prevented them from walking and/or bicycling within the last 7 days ($n=203$) were excluded from the transportation activity questions and recreational walking questions. In addition, respondents with missing data for all activity types within a single domain of activity (e.g., recreational activity) were excluded ($n=2$).

Transportation and recreational activity were analyzed as two separate outcomes because the environmental factors that influence these two forms of activity likely differ.[23] Transportation activity was analyzed using two dichotomous outcomes: (1) engaged in any versus no transportation activity (walking or bicycling) and (2) met/did not meet public health recommendations solely through transportation activity (walking or bicycling five times per week, 30 minutes per activity or per combination of activities).[24] Recreational activity was analyzed as a single dichotomous variable: met/did not meet public health recommendations solely through leisure-time activity (walking or moderate activity five times per week, ≥30 minutes per activity or per combination of activities, or vigorous activity three times per week, ≥20 minutes per activity).

Environmental measures. The environmental measures selected for this study build on work originating from an expert consensus development process carried out between October 2001 and June 2002 to identify evidence-based indicators of activity-friendly communities (Brennan Ramirez LK et al., unpublished observations, 2004). The resulting indicators included domains in the current study, which examined only physical and social environmental variables measured in parallel by the telephone survey and audit.

Perceived environmental measures. Telephone survey questions on the perceived neighborhood environment were derived largely from previous work from San Diego,[9] South Carolina,[25] and St. Louis.[26–28] Recently, researchers from these three teams completed a national assessment of the

reliability of various questions and scales for measuring the physical and social environments, which aided this study.[29] The measures are described in Table 1. Most of the survey questions used Likert- or ordinal-type response categories. Questions assessing the number of minutes required to walk from the respondent's home to the nearest of 13 specific destinations were collapsed into a single land-use measure, representing the number of such destinations within a 5-minute walk (~0.25 mile). A similar measure was derived for estimating access to six recreational facilities and the presence/absence of specific facilities (i.e., park, trail, private fitness facility) within a 5-minute walk.

Objective environmental measures. An environmental audit is a systematic assessment of factors in the physical and social environment that hinder or facilitate physical activity.[18,30] Environmental audit items were selected following review of >30 existing audit tools. Details regarding the development of the audit instrument can be found elsewhere.[21] To guide the extensive process of cleaning the audit data, detailed decision rules were developed, which are available from the lead author upon request.

Mapping the telephone survey respondents (as points) and the environmental audit data (as vectors) permitted linkage between the telephone survey and audit data. Specifically, an extension of ArcView, version 8.3 (Environmental Systems Research Institute, Redlands CA, 2002), software was created to summarize the information from street segments within a 400-m radius or buffer around each individual respondent. Only those street segments with ≥50% of their distance intersected by the buffer were included in the calculation of the summary statistics. The mean number of segments in a 400-m buffer was 47.1 (standard deviation, 21.6). Summary statistics for the audited street segments within each buffer included sums (e.g., number of nonresidential destinations), means (e.g., average physical disorder score), and frequencies (e.g., percentage of street segments with no heaves or cracks in the sidewalks). Counts were also generated for other georeferenced data, including areas (e.g., parks) within the buffer. Each of these summary variables was linked to the individual in an outputted database.

The audit-derived environmental measures used for the analysis are described in Table 1. The extent to which the audit and survey measures reflect similar environmental characteristics or constructs varies, with some measures being more directly comparable (e.g., parks, public transit, minimal garbage) than others (sidewalk measures, safety from crime).

Analysis

All statistical analyses were conducted using SAS, version 8.0 (SAS Institute Inc., Cary NC, 1999–2001). To yield stable estimates, response categories of the perceived measures were combined if the reference category (e.g., strongly disagree) contained <5% of the respondents. Cut-points for the objective environmental measures were based on quartiles or, when possible, meaningful categories. The reference categories for all of the measures represent the values hypothesized to be least associated with activity (e.g., fewest destinations, fewest recreational facilities) so that positive associations with activity might be observed.

For the descriptive analysis, chi-square statistics were generated to compare sociodemographic measures across the four study areas. Unadjusted and multivariate-adjusted odds ratios (ORs) and 95% confidence intervals (CIs) were calculated using logistic regression to compare levels of physical activity by the perceived and objective environmental measures. The models were adjusted for age, gender, and education level. Respondents missing any of these covariates were excluded from the analyses (n =15). Income was not included in the models due to the large number of missing responses (n =106) and its significant correlation with education level. Statistical interactions of the environmental indicators with gender and income area (lower vs higher income) were tested using the likelihood ratio test.[31] The extended Mantel–Haenszel correlation statistic was used to test for linear trends.[32]

In a secondary analysis, use of recreational facilities was examined both as a dependent variable of proximity to recreational facilities (using generalized linear models), and as an independent variable for meeting recommendations through recreational activity (using logistic regression). Respondents were asked, "During the last 30 days on how many days did you use the **nearest**. . ." of six recreational facilities. The present analysis only considers use of the nearest park, trail for walking or biking, and indoor fitness center.

Results

The sample of adults living in the study areas was diverse with respect to age, race/ethnicity, and educational attainment, and slightly underrepresented men (Table 2). Respondents from the lower-income study areas tended to engage in more transportation activity than those from the higher-income areas, while Savannah respondents were more likely to meet recommendations for physical activity through recreational activity than St. Louis respondents.

Patterns Among Survey and Audit Environmental Measures

Table 3 presents the number of respondents by categories of the survey measures (left side of table), the corresponding audit measures (right side of table), and the association of these measures with transportation and recreational physical activity, as indicated by the adjusted ORs. Before the associations are discussed, the frequency distributions of the environmental characteristics in the study population are briefly described.

In terms of the land-use measures, the majority of respondents (88.3%) agreed/strongly agreed that destinations were within easy walking distance from their homes (Table 3). According to the survey data, 60% of the respondents had a park, 31% had a walking or bicycling trail, and 6% reported access to an indoor fitness facility within a 5-minute walking distance from their homes. Over 90% of the respondents agreed/strongly agreed that sidewalks were present on most streets in their community; however, the condition of

Table 1. Descriptions of telephone survey and audit measures

Survey measure	Description	Audit measure	Description (within 400 m from respondent's home)
Land use			
Many destinations within walking distance	There are many destinations within walking distance from my home (Strongly disagree, disagree, agree, strongly agree)	Count of nonresidential destinations	Sum of number of nonresidential destinations, including those related to restaurants, grocery stores, schools, retail, service, automobile, employment, government, civic organizations, entertainment, religious, and health services
Count of specific destinations	Number of destinations (out of 13) in which respondent answered ≤5 minutes to the following set of questions: "How many minutes would it take you to walk to the nearest . . . [convenience or small grocery store, supermarket, laundry or dry cleaners, post office, library, elementary/junior high school, high school/college/university campus, fast food restaurant, other restaurant, coffee shop, bank or credit union, pharmacy or drug store, place of worship]?"	Count of specific destinations	Sum of number of specific types of destinations assessed by the telephone survey (subset of nonresidential destinations)
Recreational facilities			
Many places to exercise	There are many places to be physically active in my community not including streets for walking or jogging (strongly disagree, disagree, agree, strongly agree)	Count of parks with facilities	Sum of number of parks with facilities (e.g., walking trails, sports fields or courts, or playgrounds)
Any park, any trail, any private fitness facility	Respondent answered that a park, walking trail, or private fitness facility was within a 5-minute walk from home (dichotomous)	Any park, any trail, any indoor fitness facility	Presence of at least one park, walking trail, or indoor fitness facility (dichotomous)
Count of recreational facilities	Number of recreational facilities (out of seven) in which respondent answered ≤5 minutes to the following questions: "How many minutes would it take you to walk to the nearest . . . [park, public recreational center/gym/fitness facility, trail for walking or biking, schools that allow the public to use their facilities for physical activity, public swimming pool, fitness facilities that require membership]?"	Count of recreational facilities	Sum of the number of recreational facilities, including parks, trail, sports fields or courts, outdoor pools, and indoor recreational facilities
Transportation environment			
Sidewalks present	There are sidewalks on most streets in my community (strongly disagree, disagree, agree, strongly agree)	Segments with minimal cracks or heaves in the sidewalk	Percent of street segments with sidewalks with no or a little unevenness (e.g., cracks or heaves)
Bike lane present	There are bike lanes on most of the streets in my community (Strongly disagree, disagree, agree, strongly agree)	Bike lane present	Presence of at least one bike lane

Table 1. (*continued*)

Survey measure	Description	Audit measure	Description (within 400 m from respondent's home)
Public transit available	It is easy to walk to a bus stop, train, or subway station from my home (strongly disagree, disagree, agree, strongly agree)	Segments with a bus stop	Percent of street segments with a bus or other transit stop
Feel safe from traffic	How safe from traffic do you feel while you are walking or riding your bike in your neighborhood? (extremely, quite, slightly, or not at all safe)	Street safety score	Average of the street safety summary score, calculated for each street segment by summing seven audit items related to number of traffic lanes, connectivity, street design characteristics to reduce volume or speed, traffic calming devices, aggressive drivers (reverse coded), crossing aids, and street lighting (1=none, 2=a little, 3=some, 4=a lot)
Aesthetics			
Neighborhood pleasant	Rate your neighborhood as a place to be physically active (extremely, quite, slightly, or not at all pleasant)	Segments with attractive features	Percent of street segments with some or a lot of attractive features (e.g., architectural design, building variety, vegetation)
Trees along neighborhood streets	There are trees along the streets in my neighborhood (strongly disagree, disagree, agree, strongly agree)	Segments with trees, benches, or other comfort amenities	Percent of street segments with some or a lot of comfort features (e.g., shade trees, benches, or other types of amenities)
Neighborhood free of garbage, litter, or broken glass	My neighborhood is generally free from garbage, litter, or broken glass (strongly disagree, disagree, agree, strongly agree)	Segments with minimal garbage, litter, or broken glass	Percent of street segments with no or a little garbage, litter, or broken glass
Neighborhood maintained	My neighborhood is well maintained (strongly disagree, disagree, agree, strongly agree)	Physical disorder score	Average of the physical disorder summary score, calculated for each street segment by summing the weighted responses for eight audit items assessing the presence of beer or liquor bottles or cans, cigarette or cigar butts or packages, condoms, drug-related paraphermalia, garbage, litter or broken glass, abandoned cars, graffiti, and broken windows (0=none, 2=a few, 5=some, 9=a lot)
Social environment			
Feel safe from crime	How safe from crime do you feel while you are walking or riding your bike in your neighborhood (extremely, quite, slightly, or not at all safe)	Count of crime watch signs	Sum of the weighted response of an audit item assessing the presence of neighborhood or crime watch signs (0=none, 2=a few, 5=some, 9=a lot)
Neighbors physically active	A lot of people in your neighborhood are physically active (strongly disagree, disagree, agree strongly agree)	Count of people engaging in active behaviors	Sum of the weighted responses of three audit items assessing the number of teenagers or adults, children, or older adults engaging in active behaviors (0=none, 2=a few, 5=some, 9=a lot)

the sidewalks (i.e., levelness), as assessed by the neighborhood audits, varied considerably. Slightly over one third of respondents lived within 400 m of a bike lane, and, on average, approximately one in five segments

Table 2. Sample demographic characteristics and physical activity behavior, by study area

Sample characteristics	Total	St. Louis, Missouri		Savannah, Georgia		p value[a]
		Lower income (%)	Higher income (%)	Lower income (%)	Higher income (%)	
N/*n*	1053	215	245	261	332	
Male gender	34.2	21.4	34.3	37.2	40.1	**0.0001***
Age (years)						
18–24	11.6	7.0	3.3	29.5	6.6	**<0.0001****
25–44	37.5	39.1	40.8	34.9	36.2	
45–64	31.5	35.4	29.8	23.4	36.8	
≥65	19.4	18.6	26.1	12.3	20.5	
Race						
Non-Hispanic white	63.6	1.4	96.7	46.2	92.8	**<0.0001****
Non-Hispanic black	32.6	96.2	0.4	47.3	3.9	
Other	3.8	2.4	2.9	6.5	3.3	
Education						
<High school	12.5	33.5	4.9	16.1	1.8	**<0.0001****
High school	21.1	37.7	24.9	20.3	8.1	
>High school	66.3	28.8	70.2	63.6	90.1	
Any transportation activity	65.5	71.0	57.4	82.0	55.4	**<0.0001****
Met recommendations through transportation activity	21.2	21.9	14.4	35.0	15.2	**<0.0001****
Met recommendations through recreational activity	32.7	23.4	31.0	35.4	38.0	**0.0032***

[a]p value based on chi-square test for differences across the four study areas.
*p <0.005; **p <0.001 (bolded).

had a public transit stop within this distance. Over half of the respondents felt quite or extremely safe from traffic and/or perceived that their neighborhoods were pleasant, generally free from litter, and/or maintained. For the social environment measures, approximately half of the respondents felt quite or extremely safe from crime and agreed/strongly agreed that a lot of people in their neighborhood were physically active.

Associations of Audit and Survey Environmental Measures with Physical Activity

The associations of the audit and survey environmental measures with transportation and recreational activity are presented as ORs, adjusted for age, gender, and education (Table 3). Only those environmental characteristics thought to directly influence transportation and/or recreational physical activity are presented. Adjusting for city or vehicle ownership in the multivariate models did not change the ORs, and no statistically significant interactions with gender or income area were observed.

Land Use

For both the perceived and objective land-use measures, transportation activity was positively associated with having more destinations within walking distance of one's home (Table 3). Although not all ORs were statistically significant, dose–response relationships were observed for many of the land use measures. Results showed that people in the highest quartile for the total number of nonresidential destinations were two to three times more likely to engage in any transportation activity or meet recommendations through transportation activity than respondents in the lowest quartile.

Recreation Facilities

Associations between measures of recreational facilities and recreational activity were only statistically significant for some of the survey measures (Table 3). People who agreed that they had many places to exercise in their community and who reported more facilities within a 5-minute walk were slightly more likely to meet recommendations. However, the direction of the trends and significance of the associations at different levels of these recreational facility measures were inconsistent. No significant associations were observed from the audit data.

Figure 1 presents the mean number of days that respondents reported using the nearest park, walking trail, and indoor fitness facility by the presence/absence of the particular facility within a 5-minute walking distance for the survey measures and within 400 m for the audit measures. The results indicate that people who live closer to a park or trail use the facility more frequently, on average, than people who live farther from these facilities. Only the survey measure for proximity to indoor fitness facilities was associated with more facility use.

Table 3. Association between neighborhood environmental measures and transportation and recreational physical activity

	Transportation activity			Recreational activity			Transportation activity			Recreational activity	
Survey measure	N/*n*	Any aOR (95% CI)	Met rec[a] aOR (95% CI)	N/*n*	Met rec[b] aOR (95% CI)	Audit measure[c]	N/*n*	Any aOR (95% CI)	Met rec aOR (95% CI)	N/*n*	Met rec aOR (95% CI)
LAND USE											
Many destinations within walking distance						**Count of nonresidential destinations (quartiles)**					
SD/D	100	1.0	1.0	—[d]	—	0–10	233	1.0	1.0	—	—
A	370	1.2 (0.8–1.9)	0.9 (0.5–1.6)			11–22	229	1.5 (1.0–2.1)	1.3 (0.8–2.2)		
SA	384	2.0 (1.2–3.2)	1.2 (0.7–2.0)			23–42	188	2.7 (1.7–4.0)	1.7 (1.0–2.9)		
						43–131	207	**3.5 (2.3–5.5)***	**3.3 (2.0–5.4)***		
Count of specific destinations						**Count of specific destinations (quartiles)**					
0	185	1.0	1.0	—	—	0–4	310	1.0	1.0	—	—
1–3	348	1.5 (1.0–2.2)	1.2 (0.8–2.0)			5–6	167	0.7 (0.5–1.1)	0.5 (0.3–0.96)		
4–6	230	2.1 (1.4–3.2)	1.2 (0.7–2.0)			7–14	184	1.2 (0.8–1.7)	1.2 (0.8–1.9)		
7–13	80	**2.4 (1.3–4.3)***	1.3 (0.7–2.5)			15–37	196	**2.3 (1.5–3.6)***	**2.5 (1.6–3.8)***		
RECREATIONAL FACILITIES											
Many places to exercise						**Count of parks with facilities**					
SD	—	—	—	76	1.0	0	—	—	—	468	1.0
D				192	1.6 (0.8–3.0)	1				500	1.0 (0.8–1.4)
A				526	2.0 (1.1–3.7)	2–3				83	1.1 (0.6–1.9)
SA				252	1.7 (0.9–3.3)						
Any park						**Any park**					
No	—	—	—	385	1.0	No	—	—	—	317	1.0
Yes				586	1.3 (0.96–1.7)	Yes				734	1.2 (0.9–1.7)
Any trail						**Any trail**					
No	—	—	—	669	1.0	No	—	—	—	688	1.0
Yes				302	1.3 (0.97–1.7)	Yes				363	1.2(0.9–1.6)
Any private fitness facility						**Any indoor fitness facility**					
No	—	—	—	912	1.0	No	—	—	—	835	1.0
Yes				59	1.0 (0.6–1.8)	Yes				216	0.7 (0.5–1.0)
Count of recreational facilities						**Count of recreational facilities (quartiles)**					
0	—	—	—	262	1.0	0–1	—	—	—	293	1.0
1				273	1.5 (0.98–2.1)	2–3				264	1.1 (0.8–1.6)
2–3				367	1.6 (1.1–2.3)	4–5				283	0.9 (0.6–1.2)
4–6				69	**1.3 (0.7–2.3)***	6–17				211	1.0 (0.6–1.5)
TRANSPORTATION ENVIRONMENT											
Sidewalks present						**Segments with minimal cracks or heaves in the sidewalk (quartiles)**					
SD/D	52	1.0	1.0	67	1.0	0–49%	218	1.0	1.0	276	1.0
A	254	1.3 (0.7–2.5)	0.9 (0.4–1.7)	342	0.9 (0.5–1.7)	50–63%	211	0.9 (0.6–1.4)	1.2 (0.8–1.8)	262	1.1 (0.7–1.6)
SA	550	1.6 (0.9–2.9)	0.8 (0.4–1.4)	641	0.6 (0.4–1.1)	64–82%	196	0.6 (0.4–0.98)	0.8 (0.5–1.2)	242	1.0 (0.7–1.5)
						83–100%	232	**0.6 (0.4–0.9)***	**0.5 (0.3–0.8)***	271	0.8 (0.6–1.2)
Bike lane present[e]						**Bike lane present[e]**					
SD/D	618	1.0	1.0	741	1.0	No	547	1.0	1.0	674	1.0
A/SA	237	1.7 (1.1–2.8)	1.3 (0.5–3.0)	301	1.4 (1.0–1.9)	Yes	310	0.8 (0.5–1.3)	1.0 (0.4–2.3)	377	1.1 (0.8–1.4)

(continued on next page)

Table 3. Association between neighborhood environmental measures and transportation and recreational physical activity (*continued*)

	Transportation activity			Recreational activity			Transportation activity			Recreational activity	
Survey measure	**N/*n***	**Any aOR (95% CI)**	**Met rec[a] aOR (95% CI)**	**N/*n***	**Met rec[b] aOR (95% CI)**	**Audit measure[c]**	**N/*n***	**Any aOR (95% CI)**	**Met rec aOR (95% CI)**	**N/*n***	**Met rec aOR (95% CI)**
Public transit available						**Segments with a bus stop (quartiles)**					
SD/D	45	1.0	1.0	—	—	0–13%	250	1.0	1.0	—	—
A	317	1.3 (0.7–2.6)	1.3 (0.6–2.8)			14–18%	211	1.1 (0.7–1.6)	1.4 (0.9–2.3)		
SA	490	1.9 (1.0–3.5)	1.0 (0.5–2.3)			19–24%	215	1.5 (1.0–2.3)	1.4 (0.9–2.2)		
						25–53%	181	**1.5 (1.0–2.3)***	**1.6 (0.99–2.6)***		
Feel safe from traffic						**Street safety score (quartiles)[f]**					
Not at all	75	1.0	1.0	104	1.0	16.10–17.61	232	1.0	1.0	271	1.0
Slightly	240	0.7 (0.4–1.3)	0.6 (0.3–1.0)	292	1.2 (0.7–2.0)	17.62–17.93	210	1.1 (0.7–1.6)	1.2 (0.7–1.8)	260	0.9 (0.6–1.3)
Quite	413	0.8 (0.4–1.4)	0.5 (0.3–0.8)	498	1.0 (0.6–1.6)	17.94–18.14	209	0.9 (0.6–1.4)	1.0 (0.6–1.6)	265	0.8 (0.5–1.1)
Extremely	126	0.6 (0.3–1.1)	0.6 (0.3–1.2)	150	0.9 (0.5–1.6)	18.15–19.23	204	0.9 (0.6–1.4)	1.1 (0.7–1.7)	255	0.9 (0.6–1.4)
AESTHETICS											
Neighborhood pleasant						**Segments with attractive features (quartiles)**					
Not at all	52	1.0	1.0	71	1.0	0–7%	221	1.0	1.0	268	1.0
Not very	59	1.5 (0.7–3.5)	0.9 (0.4–2.1)	77	1.0 (0.5–2.1)	8–16%	219	1.3 (0.9–1.9)	1.4 (0.9–2.3)	272	1.6 (1.1–2.3)
Somewhat	318	1.3 (0.7–2.3)	0.7 (0.4–1.5)	378	0.96 (0.5–1.7)	17–24%	220	1.5 (0.99–2.2)	1.3 (0.8–2.1)	267	1.7 (1.2–2.5)
Very	424	1.3 (0.7–2.4)	0.8 (0.4–1.7)	519	1.4 (0.7–2.4)	25–50%	197	1.2 (0.8–1.8)	1.2 (0.7–2.0)	244	1.5 (1.0–2.2)
Trees along neighborhood streets						**Segments with trees, benches, or other comfort amenities (quartiles)**					
SD/D	44	1.0	1.0	62	1.0	0–2%	224	1.0	1.0	266	1.0
A	275	0.8 (0.4–1.6)	1.6 (0.7–3.7)	355	1.5 (0.8–2.9)	3–12%	216	0.9 (0.6–1.3)	0.7 (0.4–1.2)	272	0.9 (0.6–1.3)
SA	537	0.8 (0.4–1.6)	1.4 (0.6–3.3)	633	1.5 (0.8–2.8)	13–25%	211	1.1 (0.7–1.6)	1.5 (0.9–2.4)	253	1.1 (0.8–1.6)
						26–60%	206	**1.6 (1.0–2.4)***	1.4 (0.8–2.2)	260	1.3 (0.9–1.9)
Neighborhood free of garbage, litter, or broken glass						**Segments with minimal garbage, litter, or broken glass (quartiles)**					
SD	63	1.0	1.0	79	1.0	0–50%	198	1.0	1.0	264	1.0
D	128	1.0 (0.5–1.9)	0.7 (0.4–1.3)	153	1.2 (0.7–2.2)	51–84%	215	1.0 (0.6–1.6)	1.1 (0.7–1.7)	260	1.2 (0.8–1.8)
A	367	0.8 (0.4–1.4)	0.5 (0.3–0.9)	452	1.3 (0.7–2.2)	85–94%	242	0.5 (0.3–0.7)	0.6 (0.4–1.0)	291	1.1 (0.7–1.7)
SA	298	0.7 (0.4–1.3)	**0.4 (0.2–0.7)***	366	1.4 (0.8–2.4)	95–100%	202	**0.4 (0.3–0.7)***	**0.4 (0.2–0.7)***	236	1.2 (0.8–1.8)
Neighborhood maintained						**Physical disorder score (quartiles)[g]**					
SD	51	1.0	1.0	70	1.0	12.85–22.61	194	1.0	1.0	258	1.0
D	108	1.0 (0.5–2.2)	0.4 (0.2–0.8)	123	0.8 (0.4–1.5)	2.78–12.84	217	0.9 (0.6–1.5)	0.9 (0.6–1.4)	262	1.3 (0.9–1.9)
A	353	0.8 (0.4–1.6)	0.4 (0.2–0.7)	446	1.2 (0.7–2.2)	1.23–2.77	221	0.4 (0.3–0.7)	0.5 (0.3–0.8)	261	1.0 (0.7–1.6)
SA	341	0.7 (0.4–1.4)	**0.3 (0.2–0.6)***	406	1.1 (0.6–2.0)	0.00–1.22	225	**0.5 (0.3–0.8)***	**0.4 (0.2–0.7)***	270	1.0 (0.7–1.6)
SOCIAL ENVIRONMENT											
Feel safe from crime						**Count of crime watch signs (quartiles)**					
Not at all	101	1.0	1.0	141	1.0	29–62	195	1.0	1.0	235	1.0
Slightly	392	1.0 (0.6–1.7)	1.0 (0.6–1.7)	313	0.8 (0.5–1.3)	21–28	221	1.1 (0.7–1.6)	0.9 (0.5–1.4)	268	1.1 (0.8–1.7)
Quite	250	0.9 (0.5–1.4)	0.7 (0.4–1.2)	461	1.0 (0.7–1.5)	15–20	222	1.0 (0.7–1.6)	1.1 (0.6–1.7)	270	1.2 (0.8–1.8)
Extremely	108	0.9 (0.5–1.7)	1.0 (0.5–1.9)	123	1.1 (0.7–1.7)	0–14	219	1.1 (0.7–1.7)	0.8 (0.5–1.3)	278	1.3 (0.8–2.0)

(continued on next page)

Table 3. (*continued*)

	Transportation activity			Recreational activity			Transportation activity			Recreational activity	
Survey measure	N/n	Any aOR (95% CI)	Met rec[a] aOR (95% CI)	N/n	Met rec[b] aOR (95% CI)	Audit measure[c]	N/n	Any aOR (95% CI)	Met rec aOR (95% CI)	N/n	Met rec aOR (95% CI)
Neighbors physically active						**Count of people engaging in active behaviors (quartiles)**					
SD	47	1.0	1.0	66	1.0	0–46	242	1.0	1.0	296	1.0
D	247	0.8 (0.4–1.7)	0.7 (0.4–1.5)	293	1.1 (0.6–1.9)	47–63	192	1.3 (0.9–1.9)	1.3 (0.8–2.1)	236	1.1 (0.7–1.6)
A	428	0.7 (0.4–1.7)	0.7 (0.4–1.4)	508	1.2 (0.7–2.1)	64–92	214	1.2 (0.8–1.8)	1.0 (0.6–1.7)	260	1.3 (0.9–1.9)
SA	97	1.1 (0.5–2.5)	0.8 (0.4–1.9)	128	1.4 (0.7–2.7)	93–238	209	**2.1 (1.4–3.2)***	**2.7 (1.7–4.3)***	259	1.0 (0.7–1.5)

[a]Met public health recommendations solely through transportation activity.
[b]Met public health recommendations solely through recreational activity.
[c]Audit measure derived from street segments within 400 of respondent's home.
[d]Association was not assessed because the environmental measure was not thought to be directly associated with the specified form of physical activity.
[e]Associated with transportation by bicycle only.
[f]Higher scores reflect safer streets.
[g]Higher scores reflect more physical disorder.
**p* value for trend <0.05 (bolded).
A, agree; aOR, adjusted odds ratio; CI, confidence interval; D, disagree; rec, recommended; SA, strongly agree; SD, strongly disagree.

In addition, use of the facilities was associated with meeting recommendations through recreational activity. Compared with never using the park in the last 30 days, the adjusted ORs for meeting recommendations through recreational activity were 1.2 (95% CI=0.8–1.7) for using it 1 to 5 days; 2.1 (CI=1.3–3.4) for using it 6 to 10 days; and 4.3 (CI=2.9– 6.2) for using it >10 days. Similar trends were observed for use of the nearest trail, where adjusted ORs were 1.4 (CI=0.97–2.0) for 1 to 5 days; 2.4 (CI=1.4–4.1) for 6 to 10 days; and 3.4 (CI=2.2–5.1) for >10 days; and use of the nearest private fitness facility, where adjusted ORs were 1.3 (CI=0.8–1.9) for 1 to 5 days; 2.3 (CI=1.3–4.0) for 6 to 10 days; and 5.3 (CI=3.3–8.6) for >10 days.

Transportation Environment

The strength and direction of the relationships with physical activity behavior varied across the transportation environment measures. While the perceived presence of sidewalks along neighborhood streets indicated a slightly positive, but nonsignificant association with engaging in any transportation activity, the levelness of sidewalks as assessed by the audit showed a significant negative association with this outcome and with meeting recommendations through transportation activity (Table 3). The latter finding suggests that respondents with fewer cracks or heaves on the sidewalks in their neighborhood were less likely to report walking and bicycling for transportation. No associations between the sidewalk measures and recreational activity were observed. Engaging in any bicycling activity for transportation and meeting recommendations through recreational activity were significantly associated with perceiving that bike lanes were present on most streets in the community; however, they were not associated with the corresponding objective measure. Although statistical significance was not achieved for all ORs, having public transit stops was associated with engaging in transportation activity. Lastly, neither the survey nor audit measure for traffic safety was clearly associated with physical activity.

Aesthetics

Compared to respondents in the lowest quartile for no attractive features (0% to 7% of segments in the 400-m buffers), those in the second and third quartiles were about 50% to 70% more likely to engage in recommended recreational activity. Both the survey and audit measures related to minimal garbage, maintenance, and physical disorder showed consistently strong, inverse relationships with transportation activity. For example, respondents who perceived their neighborhood to be generally free from garbage, litter, or broken glass, and well maintained were about 50% to 70% less likely to meet recommendations by walking or bicycling for transportation.

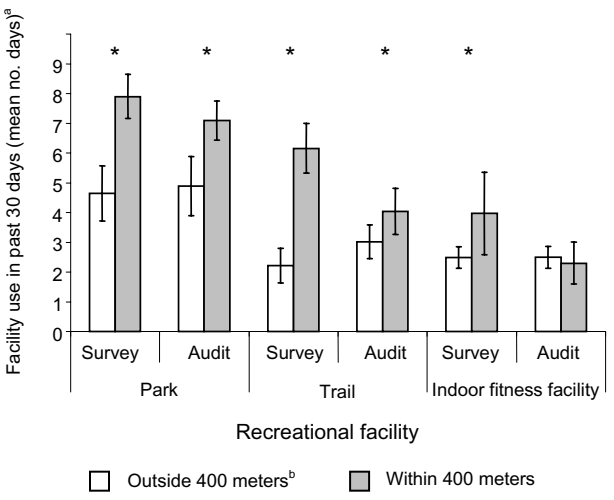

Figure 1. Relationship between use and availability of recreational facilities, derived from survey and audit data.
[a]Adjusted for age, gender, and education.
[b]Represents the distance from a respondent's home to the nearest specified recreational facility. For the survey measures, 400 m refers to a perceived 5-minute walking distance.
*$p < 0.05$.

Social Environment

Neither of the social environment measures was correlated with recreational activity. The only measure associated with transportation activity was the audit measure for the number of people observed engaging in active behaviors. Respondents with >92 active people observed within 400 m of their home (fourth quartile) were about two to three times more likely to engage in any or recommended levels of activity through transportation compared to those with <47 active people (first quartile).

Discussion

The results of this study of urban environments support some direct relationships between the environment and physical activity behavior. While both perceived and objective measures for the number of nonresidential destinations near respondents' homes were strongly and consistently correlated with physical activity, measures from other domains yielded weaker and/or nonsignificant direct associations.

Having destinations within walking distance from homes emerged as the strongest correlate of transportation activity. This finding was observed for the audit and survey measures. Consistent with studies from the urban planning literature,[33,34] this finding suggests that building communities in which nonresidential destinations are within walking distance of homes may be beneficial to health.

Associations were observed between the presence of nearby recreational facilities and use of the facilities, as well as between use of the facilities and meeting recommendations through recreational activity. However, no direct association emerged between presence of recreational facilities and meeting recommendations. These results suggest that individual-level factors and other environmental supports besides proximity must be present before a person engages in recommended levels of recreational activity. Also, people may be participating in recreational exercise at places outside their neighborhoods (e.g., work, nearby trail), and the characteristics of and distances to these locations may impact their use.[35] A study among Australian adults[36] showed similar associations with the level of access to some recreational facilities (e.g., attractive public open space, river, beach) and use of facilities. The investigators also found that physical environment measures had much weaker effects on exercising as recommended than individual and social determinants, concluding that "a supportive physical environment alone may be insufficient to increase community recreational activity levels."[36] This implies that the physical environment is a necessary but not sufficient causal factor for recreational physical activity participation.

Some of the weaker or nonsignificant associations may be attributed to characteristics of the environmental features studied, measurement error, low statistical power, or a limited direct effect of the environmental characteristic on generating physical activity. For example, the inclusion of traditional suburban neighborhoods or rural settings might have provided more variation for features with limited variation in these urban settings (e.g., sidewalk availability, street safety). The lack of an association between perceived sidewalk availability and physical activity is likely a function of the high prevalence of sidewalks in the study areas. Evidence from prior studies on the effects of sidewalk availability have been conflicting for recreational physical activity,[12,37,38] and limited for transportation activity.[39,40] Limited variation and/or a potential weakness in the audit instrument for capturing variation may account for the lack of an effect of objectively measured street safety on physical activity. Similar to previous studies of U.S. women, no association was observed between perceived safety from traffic and physical activity,[38,41] probably because feeling unsafe from traffic is experienced equally by inactive and active individuals. Auditing the environments at different times of day may have altered the association between number of people observed engaging in active behaviors and physical activity behaviors. In addition, unmeasured characteristics of safety from crime (e.g., crime incidents) may play a role in the lack of an association with physical activity, a finding that contrasts from previous studies.[12,42] Development of alternative methods is vital to improved understanding about objective assessment of the social environment.

Unmeasured income area effects may account for the two neighborhood environmental effects that seemed

contradictory. For example, income area effects may explain the inverse associations between transportation activity and both sidewalk levelness and less physical disorder, in that uneven sidewalks and physical disorder were primarily concentrated in the lower-income areas where more residents walked or bicycled for transportation. The inverse associations also imply that people engage in transportation activity despite the sidewalk's conditions or amount of physical disorder. None of the perceived measures of attractive or comfort features were associated with recreational activity, an observation that differs from many previous studies.[12,43] The differential effect of specific neighborhood environmental features on either transportation or recreational activity calls into question the use of summary measures of physical activity that combine transportation and recreational activity.

The only differences between perceived and objective measures in their association with physical activity involved measures of recreational facilities and bike lanes. It is possible that active respondents may have been more likely to perceive recreational facilities or bike lanes as accessible.[25] However, the differences may also be attributed to varying conditions of the recreational facilities or bike lanes, which is challenging to measure quantitatively. For example, respondents with neglected or unsafe facilities may not have perceived these as an option for activity, and therefore, these facilities included in the audit assessment may have had little to no effect on physical activity behavior. In this regard, perceptions may be more important than objective measures. The findings may also indicate that larger buffer sizes are required when exploring environmental correlates of some types of activity (e.g., bicycling), since, for example, a quarter mile requires less time and energy to travel by bicycle than on foot.

Although the IPAQ long form has advanced physical activity measurement by assessing multiple forms of lifestyle physical activities, it is associated with some weaknesses, including over-estimation of weekly minutes of physical activity, the inability to know whether activities occur on the same or different days, and the high respondent burden because of its length and repetition.[22] Future physical activity research must incorporate objective methods, and focus on improving self-report measures across all activity domains.

Using audits along with the buffer method to assess neighborhood environmental exposures raised some important methodologic issues. While conducting audits may be a novel approach to collecting objective data, the extent of its objectivity depends on clear protocols, comprehensive audit items, and inherent flexibility to capture the dynamic and unexpected environment. The buffer approach provided a feasible method for gauging densities of exposure within each respondent's unique neighborhood; however, it failed to capture street network characteristics or distances to features outside the buffer area. Moreover, auditing only within the study area boundaries resulted in missing environmental data for respondents whose buffers extended beyond the audited street segments. Another approach, although costly, would have been to audit the area within all of the buffers. To address this issue, respondents in the bottom quartile (by study area) for the number of segments within their 400-m buffers were excluded from the analysis. While their exclusion did not substantially change the conclusions (only six ORs changed by 10% to 20%, and three ORs changed by >20%), future analyses must examine other ways to address this important issue, such as by summarizing environmental information within block groups or using different measures to evaluate accessibility of recreational facilities and other destinations.[34,36]

In conclusion, perceived and objective measures of land use, recreational facilities, and specific transportation system features revealed positive associations with physical activity, yet the same was not true for several other environmental features. This research highlighted the importance of distinguishing between transportation and recreational physical activity because the environmental factors influencing these activities tended to differ, a point emphasized by others.[23] Overall, the results suggested that the physical environment may affect transportation activity more so than recreational activity. However, additional studies are needed to observe the dynamic influence of the neighborhood over time and across community settings.

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