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Independent and Joint Associations between Multiple Measures of the Built and Social Environment and Physical Activity in a Multi-Ethnic Urban Community

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ABSTRACT *Physical activity is associated with reduced risk of a number of health outcomes, yet fewer than half of adults in the United States report recommended levels of physical activity. Analyses of structural characteristics of the built environment as correlates of physical activity have yielded mixed results. We examine associations between multiple aspects of urban neighborhood environments and physical activity in order to understand their independent and joint effects, with a focus on the extent to which the condition of the built environment and indicators of the social environment modify associations between structural characteristics and physical activity. We use data from a stratified, multi-stage proportional probability sample of 919 non-Hispanic Black, non-Hispanic White, and Hispanic adults in an urban community, observational data from their residential neighborhoods, and census data to examine independent and joint associations of structural characteristics (e.g., street network connectivity), their condition (e.g., sidewalk condition), and social environments (e.g., territoriality) with physical activity. Our findings suggest that sidewalk condition is associated with physical activity, above and beyond structural characteristics of the built environment. Associations between some structural characteristics of the built environment and physical activity were conditional upon street condition, physical deterioration, and the proportion of parks and playgrounds in good condition. We found modest support for the hypothesis that associations between structural characteristics and physical activity are modified by aspects of the social environment. Results presented here point to the value of and need for understanding and addressing the complexity of factors that contribute to the relationships between the built and social environments and physical activity, and in turn, obesity and co-morbidities. Bringing together urban planners, public health practitioners and policy makers to understand and address aspects of urban environment associated with health outcomes is critical to promoting health and health equity.*

KEYWORDS *Built environment, Social environment, Physical activity*

BACKGROUND

Physical activity is associated with reduced risk of a number of health outcomes, including obesity, cardiovascular disease (CVD), type 2 diabetes, and some

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cancers.[1,2] Fewer than half of adults in the United States report recommended levels of physical activity.[1,3] A body of literature has examined features of suburban built environments such as low densities, street condition, and presence or absence of sidewalks as these contribute to physical inactivity and associated health outcomes.[4–7] While some research has suggested features of urban communities, such as higher population density and street connectivity, are positively associated with physical activity, physical activity tends to be lower in low-to-moderate income urban communities, despite higher densities, often quite good street connectivity, and presence of sidewalks.[8] Residents of urban neighborhoods with few economic resources may encounter other environmental conditions that may contribute to physical inactivity (e.g., poor condition of sidewalks) placing them disproportionately at risk of associated health risks.[9–11] The disproportionate representation of non-Hispanic Blacks (NHB) and Hispanics in low income urban neighborhoods adds urgency to the need to understand relationships between built and social environments and their joint implications for racial, ethnic, and socioeconomic disparities in physical activity and associated health outcomes.

We examine associations between multiple aspects of neighborhood environments and physical activity in an urban community in which the majority of residents are Hispanic or NHB. We extend earlier research examining structural characteristics of the built environment (e.g., street connectivity) and physical activity,[12] to examine their associations jointly with the condition of the built environment (e.g., sidewalk condition), and the social environment (e.g., physical disorder). To do this, we draw on a unique dataset compiled by the Detroit Healthy Environments Partnership, a community-based participatory research partnership made up of community-based organizations, health care providers, and academic researchers.[2,13]

Conceptual Model. The conceptual model (Figure 1) guiding this study adapts a multilevel framework for understanding racial, ethnic and socioeconomic health inequalities.[2,14] Broad societal processes (e.g., economic trends, land use patterns) are linked with race-based residential segregation and economic disinvestment from urban neighborhoods with high concentrations of Hispanics and NHB. Structural characteristics of the built environment, such as street layout and density, are linked to historical economic patterns (e.g., manufacturing), transportation systems, and land use. The condition of the built environment, such as maintenance of residential and commercial buildings, is influenced by economic patterns, and by social and political trends that affect investments in local infrastructure. These same trends influence the social environment, including for example, residents' social investment in the neighborhood and each other.

The conceptual model suggests that structural characteristics may influence physical activity by, for example, shaping the walkability of urban neighborhoods. Building on accumulating evidence from urban planning, transportation, and public health, physical activity for transportation (that is, walking to a destination) appears to be higher among residents of neighborhoods with mixed land uses.[15–17] Associations between density, another land use characteristic, and physical activity are mixed.[18,19] Several studies have reported higher levels of physical activity for transportation among residents of neighborhoods with higher density.[4,5,7,20–22] Associations are less consistent for overall or leisure activity,[5,21,23] and a small number of studies have reported negative associations between density and physical activity for specific population subgroups,[24] or in specific contexts.[25,26] Other structural features of neighborhoods that have been suggested to be associated with physical activity include reach, a measure of accessibility to destinations outside the neighborhood,[6,27] and connectivity and integration, measures of how well connected a neighborhood is to a broader network of streets.[28,29]

The presence of sidewalks has been associated with physical activity, but again, findings are inconsistent.[6,30–32] There is relatively little systematic evidence examining the extent to which inconsistencies may be associated with variations in the physical condition of sidewalks (e.g., good or poor condition), versus their presence or absence. Similarly, the condition of neighborhood buildings and grounds may influence the walkability of neighborhoods. Finally, while the presence of parks, playgrounds and other recreational spaces have been linked to physical activity among residents,[21] the condition of those neighborhood features may also be associated with the extent to which they are used by residents for recreational or leisure time physical activity.[33]

Associations between structural characteristics of the built environment and physical activity may also operate in conjunction with aspects of the social environment, including physical disorder[34,35] and safety.[35–38] Skogan (1990)[39] conceptualized physical disorder as visual cues, such as strewn trash or piles of dumped materials, that signal residents' investment in, or claiming of, space.[40–43] Such indicators of the degree of social order and investment in the neighborhood may influence physical activity of residents through, for example, perceptions of safety.

Note that the arrows shown in Figure 1 are illustrative and primarily show unidirectional main effects. They are not intended to demonstrate all potential relationships between components of the model, which likely include synergistic and reciprocal effects, and are more dynamic than can be readily shown in a diagram for the purposes of a specific study.[14] We also note that environments outside the local neighborhood environment likely affect physical activity, including the "activity

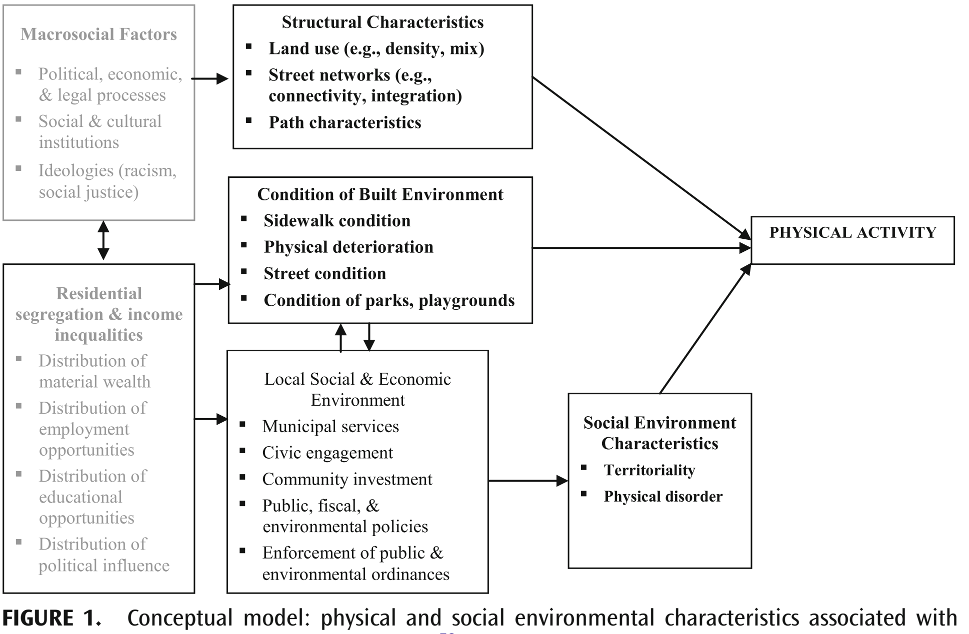

FIGURE 1. Conceptual model: physical and social environmental characteristics associated with disparities in physical activity (adapted from[59]). Items listed in *bold* are included in the analyses conducted for this paper. Note: *Arrows* are illustrative of relationships between components of the model and are not intended to provide an exhaustive representation of potential associations.

spaces" in which individuals move through daily activities, varying in size and including areas outside of their neighborhoods.[44] Thus, this model should be read as a schematic representation of a subset of neighborhood environmental characteristics that may be associated with physical activity.

Specifically, our focus is on associations between structural characteristics of the built environment (e.g., housing density) and physical activity, in conjunction with the condition of the built environment (e.g., sidewalk condition), and the social environment (e.g., physical disorder). We begin by examining main effects, to test for unique contributions of the condition of the built environment, above and beyond structural characteristics. Next, we examine whether relationships between structural characteristics and physical activity are modified by conditions of the built environment, such as sidewalk condition (e.g., are residents of neighborhoods in which surrounding streets are well connected more likely to be physically active if the condition of sidewalks is good?). Finally, we ask whether relationships between structural characteristics of the built environment and physical activity are modified by indicators of the social environment, such as physical disorder (e.g., are residents of neighborhoods in which surrounding streets are well connected less likely to be physical active if there are signs of physical disorder?).

Together, these analyses stand to contribute to our understanding of combined associations of specific features of urban built and social environments with physical activity. Understanding these joint effects may help to address some inconsistencies in previously reported findings described above. A clearer understanding of conditions that modify associations between structural characteristics and physical activity will contribute to identification of characteristics amenable to change to reduce racial, ethnic and socioeconomic inequalities associated with physical inactivity.

Study Site, Data, and Methods

Detroit offers unique opportunities to examine research questions related to the built environment and physical activity. Population out-migration reduced Detroit's population from 1.8 million in 1950 to less than half that today, simultaneously shifting the racial and economic composition of the city. Today, Detroit is characterized by a high degree of race-based residential segregation and economic divestment.[45,46] Currently, Detroit residents experience reduced probability of survival to age 65 compared to the nation[47] and a large portion of excess deaths are due to conditions related to physical inactivity (e.g., CVD, diabetes).[47] Detroit also has strengths, including residents and community- and faith-based organizations with a strong commitment to the city and the health of its residents, an active urban greenway initiative including a vibrant riverwalk along the Detroit River, and ongoing efforts to improve local food environments. Together, these factors make Detroit an important site to examine and address issues related to the built environment and health.

This study draws on a unique dataset compiled by the Detroit Healthy Environments Partnership (HEP), a community-based participatory research partnership that has been examining environmental correlates of excess CVD risk in Detroit since 2000.[2] (See Acknowledgements for further detail.) HEP's "Community-Based Participatory Research Principles" emphasize participation and influence of non-academic as well as academic partners in the design, implementation and dissemination of its efforts.[48,49] The data sources that comprise the dataset are described below, followed by a more detailed explanation of the specific measures used for this study.

Community Survey. The Wave 1 HEP survey (2002/2003) consisted of a stratified, multi-stage proportional probability sample of 919 NHB, non-Hispanic White (NHW) and Hispanic adults aged ≥25 living in three areas of Detroit. The sample was drawn to ensure adequate representation by socioeconomic position (SEP) and by racial or ethnic group status to allow meaningful comparisons across race or ethnicity, and within those groups by SEP.[2] Participants were nested within 146 census blocks and 69 census block groups. Face-to-face interviews were conducted, with data collected on a wide range of psychosocial indicators; self-reported, clinical and anthropometric health indicators; dietary intakes; and perceptions of neighborhood built and social environments.[2] All analyses were conducted applying survey weights that enable findings to be interpreted as representative of the broader population of the Detroit neighborhoods included in the study.

Neighborhood Observational Checklist (NOC) Data. The HEP database includes systematic social observation data of micro-level characteristics and conditions in all blocks in which HEP survey participants reside and adjacent blocks (n=550), collected using the NOC in 2003.[50] These observational data were used to construct environmental measures of the condition of the built environment (e.g., sidewalk condition) and the social environment (e.g., physical disorder), described below. (See[13,50,51] for further description.)

Land Use, Street, and Path Connectivity Data. Measures of structural characteristics of the built environment measures associated with each survey participant's place of residence were created by geocoding addresses and constructing measures of land use mix, accessibility of community recreational resources (e.g., recreational facilities), and street network characteristics (e.g., connectivity).

Measures

The dependent variable is physical activity (PA), assessed by asking how many days and the amount of time an individual reported walking, moderate-intensity activities (vacuuming, gardening, or anything else that causes small increases in breathing or heart rate) or vigorous activities (such as fast walking, running, dancing, or participating in strenuous sports) that cause large increases in breathing or heart rate) in a usual week for at least 10 min at a time. Based on the IPAQ,[52] an average MET weighting score was derived for each category (walking, moderate, or vigorous) of PA. "MET minutes" reflect the amount of activity and the associated energy requirements in a single measure. These values are multiples of the resting metabolic rate and a MET minute is computed by multiplying the MET score of an activity by the minutes of the time activity is performed. For walking, the weighting score was 3.3 METs, for moderate intensity activities the weighting score was 4.0 METs, and for vigorous activities the weighting score was 8.0 METs. MET minutes of each intensity level of activity was calculated for each respondent as the product of the MET weighting score, the number of days active at that intensity, and the number of minutes per day active at the intensity. The total number of MET minutes of activity was calculated for each individual as the sum of their MET minutes for walking, moderate intensity, and vigorous intensity activities per week and scaled by the standard deviation. Our analysis excludes individuals who were chair or bed bound for all or most of the day, and those from whom insufficient data was available to create the MET minutes score.

Independent variables included several observed characteristics of the neighborhood environment, including assessment of structural features, the condition of built environment features, and the social environment (conceptualized as indicators of social or human interaction with the built environment). Five structural features of the built environment were assessed: metric or distance- related measures (reach), topological or relational measures of street networks (connectivity, integration), households per acre (density), and land use mix. Conceptual and operational definitions of each of these structural characteristics are provided in Table 1.

Measures of the condition of the built environment drew upon data from the NOC described above. Each measure was constructed for the focal block in which the survey participant lived and adjacent blocks sharing a common border with the focal block (so-called "rook" neighbors). Physical deterioration[53] was measured with the following indicators: presence of vacant lots or open space, vacant non-

TABLE 1 Conceptual and operational definitions of the structural features of the built environment

Structural measure	Conceptual definition	Operational definition
Reach	Street distance covered when walking a specific distance from a single location in all possible directions.[57] Reach will be greater in areas with smaller compared to larger blocks.	A continuous measure, in miles, of the street distance covered when walking one mile from the residents' block in all possible directions. Higher scores indicate greater reach.
Connectivity	The extent to which a street is connected within its local or immediate neighborhood (See[58]).	The mean number of streets connecting with each street in the area within a ½ mile radius from survey participant's residential block. A continuous measure, with higher scores indicating greater connectivity
Integration	The extent to which a street segment or set of streets is more or less accessible from all other parts of the city (See[58]).	The mean value of the integration measure for all streets within a ½ mile radius from survey participant's residential block. A continuous measure with higher scores indicating greater integration relative to other streets in the city.
Density	A continuous number representing the mean number of residential households/acre.	The mean number of households/acre for the ½ mile radius surrounding each survey participant's residential block, based on data from the Census 2000 Summary File 1.
Land Use Mix	A measure of residential, commercial, industrial uses, with scores equal to one when land use is maximally mixed (e.g., similar proportions of multiple land uses) or heterogeneous and zero when land use is maximally homogeneous (e.g., all residential).[16,25] Created using land use data by parcel for a neighborhood.	The average land use mix for the 1/2 mile radius surrounding each survey participant's residential block, using parcel data provided by the Southeast Michigan Council of Governments (2000 and 2005). Neighborhoods in this study were primarily residential (with scores closer to zero). Higher scores reflect neighborhoods with more commercial or industrial land uses.

residential buildings, vacant residential buildings, abandoned/burned-out residential building, and the condition of most residential buildings (poor, not poor). The physical deterioration score was calculated as the mean of the proportion of block faces within each rook that had the attribute, interpreted as the average proportion of block faces with physical deterioration. Cronbach's alpha for the 6-item scale was 0.65. Sidewalk condition was the proportion of block faces in which sidewalks were in good or fair condition (range from 0=none to 1=all) and street condition the proportion of the rook streets in good or fair condition (range from 0=none to 1= all). Parks and playgrounds in good condition was calculated as the number of parks, playgrounds or recreational facilities rated to be in good or excellent condition divided by the total observed number of parks and playgrounds observed in the rook (range from 0=none to 1=all).

Measures of the social environment included physical disorder and territoriality. Physical disorder[39] was measured as the mean proportion of block faces in the rook with the presence of the following indicators: graffiti, empty beer bottles, vacant lots in poor condition, abandoned/undriveable cars, piles of garbage or dumped material, moderate or heavy strewn garbage, most residential grounds in poor condition, and most non-residential grounds in poor condition. A higher score indicates a greater proportion of block faces with one or more of these indicators. Cronbach's alpha for the 8-item scale was 0.65. Territoriality is visible cues of residents' investment in the neighborhood.[40–43] It was measured as the mean proportion of block faces in the rook with the following indicators: presence of signs (e.g., neighborhood watch, no trespassing, no dumping); residential properties with decorations (≥50 %=1), residential properties with security devices (≥50 % =1); and the proportion of vacant lots set up for socializing (e.g., with gardens, chairs) or well maintained. A higher score indicates a greater proportion of block faces with one or more of these indicators. Cronbach's alpha was 0.66.

Covariates. Level 1 (individual) control variables included age (years), sex, race/ethnicity, education, household income, length of residence in neighborhood, labor force participation, marital status, physical limitations, home ownership, and car ownership. Level 3 (census block group, an aggregation of several census blocks the smallest geographic unit at which economic data are available from the United States Census Bureau) control variables included percent of population below the poverty level, based on 2000 Census data.

Analyses

We ran three level models, using HLM: level 1 (individual), level 2 (neighborhood environmental measures at the rook level), and level 3 (percent poverty at the block group level). The use of hierarchical linear models (HLM) allows us to account for the clustering of individuals within neighborhoods and thereby obtain appropriate standard errors. We first tested associations between each measure of the condition of the built environment (e.g., sidewalk condition) and physical activity, in separate models with each structural characteristic of the neighborhood, and in models with multiple structural measures. Next, we ran separate models including interactions between each structural and each conditional measure to assess the extent to which built environment condition modified associations between structural characteristics and physical activity. Finally, we ran separate models that included interaction terms between structural measures and each measure of the social environment to assess the extent to which indicators of the social environment modified associations between structural characteristics and physical activity. All models controlled for individual covariates (level 1) and census block group poverty level (level 3).

RESULTS

Data on physical activity was examined for the sub-set of adults who reported not being chair or bed bound (n=848 of the full HEP sample of 919). Among those not chair or bed bound, a total of 697 participants reported sufficient information to calculate metabolic minutes as a measure of physical activity. Among the physically able (n=848), those with missing data (n=151) were compared to those without missing data (n=697). Chi-square and t-tests suggested no demographic differences in gender, marital status, education, race/ethnicity, poverty-to-income categorization, home ownership, car ownership, being in the labor force, age, or length of residence in the neighborhood. Descriptive characteristics of the sample are shown in Table 2, including sample frequencies, weighted proportions, means, and standard errors for block group, neighborhood/rook, and person level variables. The mean level of physical activity was 1.4 standardized metabolic minutes per week. The mean percent poverty for the block groups in which survey participants resided was 33 %. Results are presented below for each of the three main research questions.

Is the Condition of the Built Environment Associated with Physical Activity, Above and Beyond Structural Indicators?

We found a marginal positive association of integration (β=0.216, p=0.072) and a negative association of density (β=–0.029, p<0.001) with physical activity (results not shown). Next we added each indicator of the *condition* of the built environment to models with each of the structural measures separately. As shown in Table 3, sidewalk condition was positively associated with physical activity above and beyond each of the structural measures. Residents of neighborhoods in which a greater proportion of sidewalks were in good or excellent condition reported higher levels of physical activity, and this relationship remained robust after accounting for reach (β=0.508, p=0.033), integration (β=0.543, p=0.020), connectivity (β=0.493, p=0.048), density (β=0.501, p=0.038), and land use mix (β=0.539, p=0.021) in respective models. Integration was marginally positively (β=0.222, p=0.058) and density remained negatively (β=–0.025, p=0.002) associated with physical activity in models with sidewalk condition included. Sidewalk condition remained statistically significant in models that included reach, integration, density, and land use mix (connectivity was not included due to high correlations with integration) (results not shown). Physical deterioration, street condition, and presence of parks or playgrounds in good condition were not significantly associated with physical activity, above and beyond the effects of structural conditions (results not shown).

Does the Condition of the Built Environment Modify Associations between Structural Features of the Built Environment and Physical Activity?

We found no evidence that any of the measures of built environment condition examined here modified associations between reach and physical activity (results not shown). Interactions between presence of a *park or playground in good condition*

TABLE 2 Sample characteristics

	N=(697)		
Measures	Mean (s.d.)	Percent	Range
Individual characteristics (level 1)			
Age	45.4(0.9)		25–95
Female		52.1	
Married		28.6	
≥12 years education		67.1	
Race/Ethnicity			
Hispanic		21.1	
White		19.3	
Black		56.9	
Other		2.8	
Household income below poverty line		33.7	
Length of Residence in the Neighborhood	18.4(0.8)		0.7–71.0
In labor force		69.6	
Home Owner		49.4	
Car owner		70.0	
Physical Health Limitation	1.5 (0.1)		0.3–5.0
Physical Activity (Metabolic minutes, standardized)[a]	1.4 (0.1)		0–4.2
Block characteristics (level 2)			
Structural characteristics			
Reach	36.9 (7.0)		16.4–54.0
Street network connectivity	11.4 (7.1)		2.0–42.4
Street network integration	2.1 (0.3)		1.6–3.2
Land use mix	0.7 (0.1)		0.3–0.9
Density	5.4 (2.7)		2.2–24.9
Condition of built environment			
Park or playground in good condition	0.1 (0.1)		0–0.3
Physical deterioration	0.2 (0.1)		0–0.4
Street condition	0.4 (0.2)		0–0.9
Sidewalk condition	0.5 (0.2)		0–0.9
Social environment			
Territoriality	0.2 (0.1)		0–0.3
Physical disorder	0.4 (0.1)		0.1–0.6
Block group characteristics (Level 3)			
Neighborhood percent poverty (mean percent)	32.5 (12.0)		7.8–63.1

[a]Expressed in standard deviation units (standard deviation=3,569 metabolic minutes per week)

and the two relational measures of structure, connectivity (β=0.158, p=0.071) and integration (β=3.617, p=0.051), were marginally significant, with residents of neighborhoods with higher levels of integration and connectivity reporting more physical activity when a greater proportion of parks and playgrounds were in good condition.

The association between density and physical activity was modified by physical deterioration (β=−0.102, p=0.038), street condition (β=−0.044, p=0.000), and presence of park or playground in good condition (β=−0.431, p=0.024) Patterns were similar across models, with condition of the neighborhood more strongly associated with physical activity in low compared to high density neighborhoods.

TABLE 3 Physical activity regressed on sidewalk condition with reach, integration, connectivity, density and entropy, adjusting for individual characteristics, and neighborhood poverty[a]

	Model 1		Model 2		Model 3		Model 4		Model 5	
	B	s.e.	B	s.e.	β	s.e.	β	s.e.	β	s.e.
Intercept	1.130***	0.321	1.455***	0.181	1.445***	0.181	1.447***	0.180	1.452***	0.182
Condition of built environment										
Sidewalk condition	0.508*	0.237	0.543*	0.231	0.493*	0.248	0.501*	0.240	0.539*	0.230
Structural characteristics of built environment										
Reach	0.008	0.268								
Integration			0.222	0.116						
Connectivity					−0.008	0.007				
Density							−0.025**	0.008		
Entropy									0.077	0.224
Sigma-squared	0.78713		0.78573		0.78632		0.7843		0.78606	
Tau pi	0.03205		0.02873		0.02982		0.03259		0.03497	
Tau beta	0.03557		0.03962		0.03903		0.03985		0.03687	

[a]Models adjusted for age, gender, education, race and ethnicity, household poverty, physical limitations, home ownership, car ownership, length of residence in the neighborhoods, labor force participation, and neighborhood percent poverty.

*$p<.05$; **$p<.01$; ***$p<.001$

Do Indicators of the Social Environment Modify Relationships between Structural Features of the Built Environment and Physical Activity?

Territoriality modified associations between reach and physical activity (β=−0.195, p=0.033), with reach positively associated with physical activity when territoriality was low, and negatively associated with physical activity under conditions of high territoriality. In addition, our findings suggest that higher levels of physical disorder exacerbate negative associations between density and physical activity (β=−0.074, p=0.041).

DISCUSSION

There are three main findings from the results presented here. First, we found that the condition of sidewalks is associated with physical activity, above and beyond structural characteristics of the built environment. Second, our findings suggest that street condition, physical deterioration, and presence of parks and playgrounds in good condition, but not sidewalk condition, modify associations between some structural characteristics of the built environment and physical activity. Finally, our findings lend modest support for the hypothesis that observed indicators of the social environment modify associations between structural characteristics and physical activity. We discuss each finding in greater detail below.

Condition of the built environment and structural features of the built environment. Residents of neighborhoods with a greater proportion of sidewalks in good condition reported higher levels of physical activity compared to those with fewer sidewalks in good condition. This relationship remained significant in models accounting for reach, connectivity, integration, density and land use. These findings extend previous research reporting that presence of sidewalks is associated with physical activity, suggesting that sidewalk condition is a robust predictor of physical activity, above and beyond structural characteristics of the neighborhood environment. A marginal positive association between integration and physical activity, after accounting for sidewalk condition, is consistent with the idea that neighborhoods that are better connected or accessible to other parts of the city may be more positively associated with physical activity.[22,24,25,28,29]

The negative association between density and physical activity reported here joins mixed reports in the extant literature.[22,24–26,54] Our measure of overall physical activity, which does not distinguish among form (e.g., walking, biking), purpose (e.g., transportation, recreation), or location (e.g., at work, in the neighborhood) of physical activity may contribute to these differences, as previous studies have reported the most consistent positive associations between density and physical activity for transportation, [4,7,19,20] with more variable results for overall or leisure-time physical activity.[5,21,23] In addition, there is some evidence that associations between density and physical activity may vary according to other built environment characteristics (e.g., land use mix).[25,55] In the following section, we discuss some factors that may also contribute to these differential findings.

Condition of the built environment as modifiers of associations between structural characteristics of the built environment and physical activity. Our findings offer modest support for the hypothesis that condition of the built environment modifies relationships between structural characteristics and physical activity. Although only marginally significant, our findings suggest that positive associations of street network connectivity and integration with physical activity may be contingent upon the availability of parks and playgrounds in good condition in the neighborhood. Specifically, in neighborhoods with higher levels of connectivity or integration, the presence of parks or playgrounds in good condition is marginally associated with higher levels of physical activity.

Similarly, we found that both street condition and physical deterioration modified the negative association between density and physical activity. In both cases, there was a stronger effect of the moderator (street condition, physical deterioration) in low compared to high density neighborhoods. Thus, in addition to differences in measures of physical activity described above, the negative association between density and physical activity found in this sample[25] may reflect in part, variations in other neighborhood conditions, such as condition of the street, or physical deterioration. Together, our findings are consistent with others who have suggested that, while higher density may have many benefits, the extent to which it is associated with physical activity may vary with other features of the built and social environment, such as land use mix,[25] density,[26] and individual characteristics.[24,54]

Social environment as modifiers of associations between structural features of the built environment and physical activity. Finally, findings reported here lend modest support to the hypothesis that associations between the structural characteristics of the built environment and physical activity may be contingent upon social environments. Our findings suggest that reach may be associated with higher levels of physical activity only under conditions of low territoriality. High territorial markers have been interpreted as creating clearly defined ‘defensible space’ that tends to discourage strangers and keep an area safer.[43] Our finding that reach is positively associated with physical activity only under conditions of low territoriality appears to some extent to be inconsistent with this theory. It is plausible that high reach neighborhoods with fewer indicators of territoriality reflect social conditions in which residents feel less need to claim or defend the space (e.g., greater perceived safety) and therefore greater comfort in being active in the neighborhood. In contrast, neighborhoods characterized by high reach and high territoriality may be indicative of social environments in which residents are less comfortable being physically active, for example, due to an increased perceived need to claim space. The patterns reported here suggest the need for further study in order to more clearly understand associations between structural indicators and physical activity under different social contexts, as well as in conjunction with each other.

Limitations

There are a number of limitations of the analyses reported here. First, the data are cross sectional, and therefore cannot be interpreted as indicative of causality or order of effects. As illustrated in the discussion of modifying effects of territoriality on associations of reach and entropy with physical activity, the direction or order of relationships cannot be disentangled. Furthermore, there may be reciprocal relationships among variables which cannot be assessed or ruled out based on the data available for this analysis. There may have been minor changes in levels of neighborhood poverty between the time of the 2000 census and data collection for this study (2002/2003). Given our use of neighborhood poverty as a control rather than a key analytic variable, any such changes are unlikely to have substantially influenced the results reported here.

In addition, our measure of physical activity is self-reported and global, introducing limitations in terms of both accuracy and specificity. This global or general measure of physical activity does not distinguish between physical activity for transportation (e.g., walking or biking to travel from one place to another) versus recreational or leisure. Several measures of the built environment have previously been associated with physical activity for transportation (e.g., density), with others more clearly associated with recreational activity (e.g., recreation centers). The analyses reported here are unable to distinguish among type of physical activity, which may reduce the strength of some associations. Furthermore, recent conceptual and empirical research has introduced the concept of activity spaces, or the total areas in which individuals may travel over the course of a day.[44,56] This conceptual and empirical work emphasizes that individuals' physical activity is not limited to their residential neighborhoods, but may occur in a wider range of locations. Physical activity that occurs in places other than the residential neighborhood would not be expected to be affected by characteristics of the local environment. The inability to determine whether reported physical activity occurred in the residential neighborhood or not may diminish the strength of some of the associations in this study. A replication of this analysis using databases in which it is possible to distinguish between activities that take place in the residential neighborhood and those occurring outside the neighborhood would help to sharpen our understanding of the associations reported here.

Concluding Comments

Despite these limitations, the findings reported here contribute to the literature in several ways. First, they confirm associations between several structural characteristics of the neighborhood environment, both as main effects and in interaction with other characteristics of the environment. Second, they extend cross-sectional multilevel analyses by examining the relative impact of multiple indicators of the built environment (e.g., is sidewalk condition a more important predictor of physical activity than density?) as well as relationships among those built environment measures (e.g., do relationships between density and physical activity vary according to measures of physical condition of the built environment?). The finding that associations between density and physical activity are modified by several features of the built and social environment offer some insights into potential factors that may contribute to mixed results reported in the extant literature. Third, the finding that measures of the social environment (physical disorder, territoriality) modify associations between several structural characteristics and physical activity suggest that a focus on the built environment alone, while perhaps necessary, may be insufficient to capture the environmental conditions associated with physical activity among residents.

The growing health burden of obesity and co-morbidities, and their disproportionate implications for low income, Hispanic and NHB populations, highlight the need to identify the pathways through which the built environment influences population health. Understanding the joint associations of built and social environments with physical activity will be essential in order to better inform effective interventions and policies to create healthier environments. Results presented here point to the value of and need to understand and address the complexity of factors that contribute to relationships between the built and social environments and physical activity in urban communities. It is critical that researchers from multiple disciplines work with, for example, urban planners, public health practitioners and policy makers to bring about identified changes in the urban environment that impact health inequities.

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