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Neighborhood built environment and income: Examining multiple health outcomes

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ABSTRACT

There is growing interest in the relation of built environments to physical activity, obesity, and other health outcomes. The purpose of the present study was to test associations of neighborhood built environment and median income to multiple health outcomes and examine whether associations are similar for low- and high-income groups. This was a cross-sectional study of 32 neighborhoods in Seattle, WA and Baltimore, MD regions, stratified by income and walkability, and conducted between 2001 and 2005. Participants were adults aged 20–65 years ($n = 2199$; 26% ethnic minority). The main outcomes were daily minutes of moderate-to-vigorous physical activity (MVPA) from accelerometer monitoring, body mass index (BMI) based on self-report, and mental and physical quality of life (QoL) assessed with the SF-12.

We found that MVPA was higher in high- vs. low-walkability neighborhoods but did not differ by neighborhood income. Overweight/obesity ($BMI \geq 25$) was lower in high-walkability neighborhoods. Physical QoL was higher in high-income neighborhoods but unrelated to walkability. Adjustment for neighborhood self-selection produced minor changes. We concluded that living in walkable neighborhoods was associated with more physical activity and lower overweight/obesity but not with other benefits. Lower- and higher-income groups benefited similarly from living in high-walkability neighborhoods. Adults in higher-income neighborhoods had lower BMI and higher physical QoL.

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1. Introduction

Physical inactivity and obesity are prevalent and serious health challenges, contributing to cardiovascular diseases, certain cancers, diabetes, and mental disorders (Andersen, 2003; Dishman, Washburn, & Heath, 2004). Physical activity and obesity have been linked with physical attributes of neighborhoods. Neighborhoods considered walkable have non-residential destinations (e.g., shops) close to residences and well-connected streets. Low-walkability areas separate residences from destinations and have poorly connected street networks, so walking to destinations is difficult. People walk and bicycle more for transportation in high-

walkability than low-walkability neighborhoods, as indicated by multiple reviews (Gebel, Bauman, & Petticrew, 2007; Heath et al., 2006; Transportation Research Board and Institute of Medicine, 2005). There is a need to confirm whether more walkable neighborhoods are associated with higher total physical activity, particularly using objective measures of environment and activity (Frank, Andresen, & Schmid, 2004), because total physical activity should be most closely related to health benefits. A few studies indicate adults living in high-walkability neighborhoods or regions are less likely to be overweight or obese than those living in low-walkability areas (Papas et al., 2007), but further studies are needed.

Because disparities in health outcomes (Centers for Disease Control and Prevention, 2004) and physical activity are well documented across socioeconomic groups (Crespo, Smit, Andersen, Carter-Pokras, & Ainsworth, 2000), an important question is whether favorable built environments could reduce health disparities. Findings that walkability was related to physical activity and

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obesity among whites but not blacks (Frank, Andresen, & Schmid, 2004; Frank, Sallis, Chapman, & Saelens, 2005) raise the possibility that not all groups benefit from walkable built environments. Because a primary health objective of the United States is to eliminate health disparities (United States Department of Health and Human Services, 2000), it is important to determine whether walkability has similar associations with health outcomes in lower- and higher-income groups.

Advocates of walkable communities propose additional health benefits that have not been examined empirically (Duany, Plater-Zyberk, & Speck, 2000; Frank, Engelke, & Schmid, 2003; Frumkin, Frank, & Jackson, 2004). One hypothesis is that suburban residents who drive everywhere have fewer chances to form bonds with neighbors, negatively impacting social cohesion (Wood et al., 2008). Inadequate social networks are a risk factor for depression (Kawachi & Berkman, 2001), so residents of low-walkability neighborhoods might have more depressive symptoms. Some claim overall quality of life is higher for people living in walkable communities (Duany et al., 2000; Frumkin et al., 2004).

The present study investigated how living in high- vs. low-walkability and high- vs. low-income neighborhoods was related to adults' biological, behavioral, social, and mental health outcomes. Because self-selection to neighborhood has been identified as a potential confounder of associations with walkability (Transportation Research Board and Institute of Medicine, 2005; Handy, Cao, & Mokhtarian, 2006; Frank, Saelens, Powell, & Chapman, 2007; Eid, Overman, Puga, & Turner, 2007), analyses were conducted with and without adjusting for participants' reasons for moving to their current neighborhoods.

2. Method

2.1. Study design

The neighborhood quality of life study (NQLS) is an observational epidemiologic study designed to compare multiple health outcomes among residents of neighborhoods stratified on "walkability" characteristics and median household income. Data were collected from 2001 to 2005 in two metropolitan areas in the United States that were chosen based on availability of parcel-level land use information, and variability in walkability. The King County-Seattle, WA and Baltimore-Washington DC regions met these criteria.

Participants were recruited from 32 neighborhoods; 16 from Seattle-King County and 16 from Baltimore-Washington DC regions. Table 1 defines quadrants formed by low vs. high levels of walkability and low vs. high levels of income, an indicator of

socioeconomic status (SES). The study was approved by Institutional Review Boards at participating academic institutions, and participants gave written informed consent.

2.2. Neighborhood selection

Land use variables were used to compute a "walkability index" based on conceptual (Frank & Engelke, 2001) and empirical literature (Cervero & Kockelman, 1997; Saelens, Sallis, & Frank, 2003) that identify residential density, mixed land use, and street connectivity as key components of walkability. Building setbacks from the street or sidewalk are also important aspects of pedestrian-oriented design (Cervero & Kockelman, 1997). Thus, retail floor area ratio (retail building square footage divided by retail land square footage) was included in the index, with a higher ratio indicating a more pedestrian-oriented design and lower ratios suggesting more land area devoted to parking. Although other environmental variables have been related to active transport, such as sidewalks, traffic calming, and intersection characteristics (Cervero & Kockelman, 1997; Saelens, Sallis, & Frank, 2003; Handy, Boarnet, Ewing, & Killingsworth, 2002), these variables are not widely available.

The census block group was chosen as the most appropriate geographical scale to develop walkability measures for neighborhood selection. For each block group, the walkability index was derived as a function of four variables: (a) *net residential density* (ratio of residential units to the land area devoted to residential use); (b) *retail floor area ratio* (FAR; described above, indicating pedestrian-oriented design); (c) *land use mix* (diversity of land use types per block group; normalized scores ranged from 0 to 1, with 0 being single use and 1 indicating an even distribution of floor area across five uses—residential, retail, entertainment, office, institutional); and (d) *intersection density* (connectivity of street network measured as the ratio of number of intersections with three or more legs to land area of the block group in acres). Though this intersection density measure undercounts intersections on roads that form the edge of blockgroups, this particular metric was one of the best predictors of active transportation in an examination of multiple connectivity measures (Dill, 2004). The absolute count of intersections may not be entirely accurate, but the metric should be more than adequate for the present purpose of ranking blockgroups and neighborhoods.

Standardized scores for each measure were calculated separately for each region, so variables were normalized for the distributions in each region. The walkability index was a weighted sum of z-scores of the four normalized urban form measures as stated in the following expression:

Table 1
Neighborhood quality of life study design: neighborhood walkability and median household income by quadrant.

			Low-walkability		High-walkability	
			Mean	Stand. Dev.	Mean	Stand. Dev.
Low-income			8 neighborhoods (4 per region)		8 neighborhoods (4 per region)	
Seattle-King County	Walkability index		0.03	1.23	5.36	2.68
	Neighborhood household income		\$47,531	\$3679	\$36,562	\$4275
Baltimore-Washington DC	Walkability index		-0.51	0.19	1.42	0.99
	Neighborhood household income		\$42,636	\$1577	\$37,258	\$3047
High-income			8 neighborhoods (4 per region)		8 neighborhoods (4 per region)	
Seattle-King County	Walkability index		-1.92	0.71	2.93	1.24
	Neighborhood household income		\$74,576	\$8980	\$70,546	\$10,493
Baltimore-Washington DC	Walkability index		-0.74	0.16	1.55	1.44
	Neighborhood household income		\$80,098	\$8180	\$72,013	\$9634

Walkability index in z-score units; neighborhood median household income from 2000 Census data for the selected blockgroups (see Neighborhood selection section).

$$\begin{aligned} \text{Walkability} = & [(2 \times z - \text{intersection density}) \\ & + (z - \text{net residential density}) \\ & + (z - \text{retail floor area ratio}) \\ & + (z - \text{land use mix})] \end{aligned}$$

The walkability index is described in more detail elsewhere (Frank et al., *in press*). This walkability index was compared against census journey to work data from 2000 in Seattle and Baltimore regions. Higher walkability was significantly associated with less driving and more walking to work (Frank et al., *in press*). More importantly, use of the walkability index is supported by at least 12 published papers showing the same or similar indexes have been significant positive correlates of walking and physical activity (Frank, Andresen, & Schmid, 2004; Frank, Schmid, Sallis, Chapman, & Saelens, 2005; Frank et al., 2006; Frank et al., 2008; Frank, Kerr, & Sallis, 2007; Frank, Saelens, Powell, & Chapman, 2007), including studies in Australia (Cerin, Leslie, DuToit, Owen, & Frank, 2007; Leslie et al., 2007; Owen et al., 2007) and studies of youth (Kerr et al., 2006; Kerr, Frank, Sallis, & Chapman, 2007; Kligerman, Sallis, Ryan, Frank, & Nader, 2007).

Correlations among walkability component scores, with data pooled across both regions, were modest, ranging from 0.04 (land use mix—intersection density) to 0.31 (retail FAR—intersection density). Correlations of the individual components with the walkability index ranged from 0.46 (net residential density) to 0.80 (intersection density). Thus, each component contributed substantial independent variance to the walkability index, and all correlations were positive, as expected. Walkability index values ranged from -1.29 to 8.28 in the Seattle region and from -1.57 to 8.17 in the Baltimore-Washington, DC region, demonstrating substantial and similar variation in both regions.

The walkability index and census-based demographic data were used to select neighborhoods. Block groups are smaller units of geography than tracts and were selected in contiguous clusters that approximated neighborhoods. Because U.S. cities have among the lowest walkability in the world (Newman & Kenworthy, 1991), it is essential to systematically select neighborhoods to produce wide variation. Block groups in King County, WA and five counties in the Baltimore-Washington, DC region were ranked and divided into deciles based on the normalized walkability index within each region. Block groups were categorized into “high-income” and “low-income” based on 2000 Census median household income data. Block groups with median household incomes less than \$15,000 or greater than \$150,000 were excluded, to avoid outliers in neighborhood incomes. The 2nd, 3rd, and 4th deciles constituted the “low-income” category; the 7th, 8th, and 9th deciles made up the “high-income” category; the 5th and 6th deciles were omitted to create separation between the categories.

The “walkability” and income characteristics of each block group were crossed with each other (low-/high-walkability \times low-/high-income) to produce a list of block groups that fit into one of four quadrants. Clusters of contiguous block groups approximated neighborhoods and were flagged for potential selection. A geographic distribution of neighborhoods was desired in each region to enhance diversity of racial/ethnic composition, access to transit, housing types, and access to employment. Each of the 32 neighborhoods was composed of two to 13 census block groups. The goal was to define “neighborhoods” with similar numbers of households, understanding that in all cases low-walkability neighborhoods would be geographically larger than high-walkability neighborhoods. Though adjacent block groups varied in walkability, overall variation was much greater between neighborhoods than across block groups within neighborhoods. To avoid

“boundary” problems with very different walkability characteristics just outside the defined neighborhoods, investigators personally inspected all the candidate blockgroups (“ground-truthing”), so final selections were made based on both GIS walkability data and inspection. For example, if a low-walkability blockgroup had a substantial shopping area close by but in another block group, that candidate block group was excluded from the study. Table 1 shows for each region the average values and standard deviations in the walkability index and median household income for the block groups in each quadrant. Additional characteristics of study quadrants and neighborhoods are available in Frank et al. (*in press*).

2.3. Participant recruitment and assessment procedures

Recruitment and data collection were conducted during two 18 month phases. During *Phase 1* (May 2002–November 2003), participants in the Seattle/King County region were recruited and assessed. During *Phase 2* (December 2003–June 2005), participants in the Baltimore/Maryland region were recruited and assessed. In each phase, participants were recruited during the first 12 months, and a second assessment of physical activity was conducted six months later to control for season. Within each phase, participants were recruited across all neighborhoods simultaneously to further prevent seasonal bias.

Contact information of people residing within selected neighborhoods was obtained from a marketing company. Records were randomly selected within each neighborhood, and a letter introducing the project was mailed to heads of households, followed by telephone calls. If the initially-targeted adult refused or was ineligible, another adult in the household was invited. Eligibility was defined as being between 20 and 65 years, not residing in a group living establishment (e.g. nursing home, dormitory), ability to complete written surveys in English, and absence of a medical condition that interfered with the ability to walk.

After a participant returned a signed informed consent, they were mailed an accelerometer (with instructions for wearing and mailing back) to obtain an objective assessment of physical activity. A survey was mailed to the participant so he/she received it on the last day they were supposed to be wearing the accelerometer, so survey content would not influence physical activity. Participants were given the option of completing surveys by mail, online, or telephone interview. Six months later, an accelerometer and a different survey were sent for assessment in a different season. Upon receipt of accelerometer and survey data, incentive payments were mailed; \$20 for the first assessment and \$30 for the second.

2.4. Measures

2.4.1. Total physical activity

Actigraph (Actigraph, Inc; Fort Walton Beach, FL) model 7164 or 71256 accelerometers, with established reliability and validity (Welk, 2002) were used to objectively assess moderate-to-vigorous physical activity (MVPA). Participants were instructed to wear the accelerometer snugly around the waist for 7 days on each measurement occasion. The accelerometer was set to record intensity of movement each minute. A valid accelerometer hour was defined as having no more than 30 consecutive ‘zero’ values, and a valid day consisted of 10 valid hours. If there were not at least 5 valid days or a minimum of 66 valid hours across 7 days, the participant was asked to re-wear the accelerometer. On valid days, each minute was scored as meeting or not a criterion of at least moderate intensity physical activity based on published cutpoints (Freedson, Melanson, & Sirard, 1998). Average daily minutes of MVPA was the summary variable used in analyses.

2.4.2. Walking for transportation and leisure

Items from the long version of the International Physical Activity Questionnaire (IPAQ; <http://www.ipaq.ki.se>), shown to be reliable and valid (Craig et al., 2003), were used to assess transportation and leisure walking. The transportation walking items queried number of days during the last week spent walking at least 10 min from place to place and the typical minutes per day. Similarly structured items queried time in leisure walking. Total minutes per week (days \times minutes per day) were calculated.

2.4.3. Body mass index (BMI)

Self-reported weight and height was used to calculate BMI (kg/m²). Overweight was defined as BMI \geq 25 and obesity as BMI \geq 30 (National Institutes of Health, & National Heart Lung and Blood Institute, 1998).

2.4.4. Quality of life and psychosocial variables

The 12-item Short-Form Health Survey (SF-12; <http://www.sf-36.org>) was used to assess physical quality of life (QoL) and mental QoL (Ware, Kosinski, & Keller, 1996). The Center for Epidemiologic Studies' 20-item depression scale (CES-D) assessed depressive symptoms (Radloff, 1977). Perceived neighborhood social cohesion was assessed using a five-item scale (Sampson, Raudenbush, & Earls, 1997). Neighborhood satisfaction was defined as the mean of 17 ratings of satisfaction with aspects of walkability and transportation, social interaction, traffic and crime safety, and school quality. Each item was rated using a five-point scale from strongly dissatisfied (1) to strongly satisfied (5) on a scale developed by the investigators.

2.4.5. Covariates

Demographic covariates assessed by the survey were gender, age, education (five levels from less than high school to graduate degree), ethnicity (re-categorized as non-Hispanic white or non-white), number of motor vehicles/adults in household, marital status (re-categorized as married/living together or other), number of people in household, and years at current address.

To control for walkability-related self-selection of neighborhoods, a scale (internal consistency $\alpha = 0.76$) of "reasons for moving" to the current home was computed by averaging ratings of importance of three items; "desire for nearby shops and services," "ease of walking," and "closeness to recreational facilities" (adapted from Frank et al., 2007).

2.5. Statistical analyses

Mixed effects regression models (using SAS PROC MIXED) were fitted for all continuous variables, and generalized linear mixed models (using SAS PROC GLIMMIX) were fitted for the dichotomous overweight/obesity outcomes. For MVPA, the IPAQ variables (natural-log transformed because of skewness), BMI, and weight status, two time points were available for analysis. Therefore, a repeated measures framework was used for these variables. The analyses took neighborhood clustering into account, so three-level multilevel models were fitted to account for repeated measures nested within subjects and subjects nested within neighborhoods. For the remaining variables in which only one time point was available, a two-level data structure was used where subjects were nested within neighborhoods, and mixed effects regression models were fitted. All analyses were carried out using SAS version 9.1.3.

The primary exposures of interest were the quadrants constructed by crossing high-/low-walkability neighborhoods with high/low-income neighborhoods. The main effects of walkability and income and their interaction were the main focus of these analyses. All models were adjusted for the demographic covariates

and study region (Seattle, Baltimore areas). Results are reported before and after including reasons for moving as a covariate.

3. Results

3.1. Participant characteristics and representativeness

Data were collected from 2199 participants from 32 neighborhoods. Demographics of the study sample by quadrant are reported in Table 2. The sample was well balanced by sex, mostly well-educated, most were married, and 26% were non-white.

A total of 8504 eligible adults were contacted by phone. The study participation rate (i.e., returned survey 1/eligible contacts) was 26% overall and did not differ by quadrant (range of 23–29% by quadrant). The 6 month retention rate was 87% overall (range of 84–88% by quadrant), after eliminating those who were no longer eligible (e.g., because they moved out of the region). Comparisons of participant demographics with census data showed the study sample was older (median age, 45.1 vs. 35.7 years, $p < 0.01$), had fewer females (48.2% vs. 51.8%, $p = 0.03$), more whites (74.0% vs. 65.1%, $p < 0.01$), fewer Hispanics (3.7% vs. 5.6%, $p < 0.01$), and higher household incomes (median incomes, \$60–\$69,000 vs. \$50–\$59,000, $p < 0.01$) than residents of the census block groups in which participants lived.

3.2. Neighborhood walkability and income effects

Differences among participants living in neighborhoods in the high- vs. low-walkability and high- vs. low-income quadrants are shown in Table 3. Quadrant means were adjusted for covariates. Significance levels for the walkability-by-income interactions and the walkability and income main effects for each outcome are indicated.

3.2.1. Total moderate and vigorous physical activity (MVPA)

The walkability main effect was highly significant ($p = 0.0002$). On average, participants in high-walkability neighborhoods had 5.8 more min per day of objectively measured MVPA than those in low-walkability neighborhoods.

3.2.2. Walking for transport

The walkability-by-income interaction ($p = 0.027$) and walkability main effect ($p = < 0.0001$) were both significant. Overall, the significant walkability main effect indicated a higher average number of minutes per week of walking for transportation in high-walkability neighborhoods (44.3 min per week) compared to low-walkability neighborhoods (12.8 min per week). Walking for transportation was significantly higher in high-walkability neighborhoods compared to low-walkability neighborhoods for both high- and low-income neighborhoods; however, the differential was larger in high-income neighborhoods (5.1 min) vs. low-income neighborhoods (2.3 min).

3.2.3. Walking for leisure

The walkability main effect was significant ($p = 0.012$), with people living in high-walkability neighborhoods averaging 18.5 min per week of leisure walking compared to 14.2 min per week in low-walkability neighborhoods.

3.2.4. Body mass index

The income main effect ($p = 0.003$) indicated that participants living in lower-income neighborhoods had higher average BMI's (27.4) than those in higher-income neighborhoods (26.4).

Table 2

Descriptive statistics for demographic variables stratified by neighborhood income and walkability quadrants.

	Low-walkability/ low-income			Low-walkability/ high-income			High-walkability/ low-income			High-walkability/ high-income			Total			
	N	Mean	SD	N	Mean	SD	N	Mean	SD	N	Mean	SD	N	Mean	SD	
Age	532	45.8	10.7	566	45.4	10.4	526	42.3	11.4	572	46.5	11.0	2196	45.1	11.0	
# people in household (adult and children)	531	2.6	1.5	564	3.1	1.4	523	2.3	1.4	573	2.4	1.2	2191	2.6	1.4	
Sex:	N		%		N		%		N		%		N		%	
Male	246	46.2		324	57.2		270	51.4		299	52.2		1139	51.8		
Female	287	53.9		242	42.8		255	48.6		274	47.8		1058	48.2		
Education:																
Did not complete HS	9	1.7		3	0.5		18	3.4		6	1.1		36	1.6		
Completed HS	66	12.5		24	4.3		56	10.7		11	1.9		157	7.2		
Some college/vocational	192	36.2		128	22.7		170	32.4		85	14.9		575	26.2		
Completed college	157	29.6		230	40.8		171	32.6		204	35.7		762	34.8		
Graduate degree	106	20.0		179	31.7		110	21.0		266	46.5		661	30.2		
Race/ethnicity:																
Caucasian	314	59.5		451	80.3		340	65.3		511	89.3		1616	74.0		
African American	139	26.3		43	7.7		100	19.2		9	1.6		291	13.3		
Asian American	31	5.9		30	5.3		27	5.2		23	4.0		111	5.1		
Hispanic	21	4.0		21	3.7		20	3.8		19	3.3		81	3.7		
Other	23	4.4		17	3.0		34	6.5		10	1.8		84	3.0		
Marital status:																
Married	257	48.5		421	74.7		210	40.0		341	59.6		1229	56.1		
Widowed/divorced/ Separated	127	24.0		66	11.7		91	17.3		93	16.3		377	17.2		
Single/never married	114	21.5		57	10.1		175	33.3		108	18.9		454	20.7		
Living with partner	32	6.0		20	3.6		49	9.3		30	5.2		131	6.0		

3.2.5. QoL and depression

The income main effect was significant ($p = 0.006$), with participants living in higher-income neighborhoods reporting higher physical QoL scores than those living in lower-income neighborhoods (53.4 vs. 52.3, respectively). There were no significant findings for mental QoL and depression.

3.2.6. Neighborhood satisfaction

The income main effect was highly significant ($p < 0.0001$), with participants living in higher-income neighborhoods reporting

higher average neighborhood satisfaction than those living in lower-income areas (3.95 vs. 3.52, respectively). The trend ($p = 0.07$) for an income-by-walkability interaction indicated somewhat higher neighborhood satisfaction scores in high-walkability vs. low-walkability areas but only in higher-income neighborhoods; there were negligible differences for lower-income neighborhoods.

3.2.7. Social cohesion

The income main effect was significant ($p < 0.0001$), with participants in higher-income neighborhoods reporting higher

Table 3

Primary results showing adjusted means by study quadrant and tests of hypotheses for neighborhood income and walkability and the interaction unadjusted for "reasons for moving here" scale.

Outcome	Adjusted means (SE) ^a				Tests of hypotheses (p -values)		
	Low-walkability/ low-income	Low-walkability/ high-income	High-walkability/ low-income	High-walkability/ high-income	Income \times walkability interaction	Income main effect	Walkability main effect
Moderate-to-vigorous physical activity (min per day)	28.5 (1.6)	29.0 (1.6)	33.4 (1.6)	35.7 (1.6)	0.57	0.36	0.0002
Transport walking (antilog min per week)	15.6 (1.2)	10.5 (1.2)	36.2 (1.2)	53.5 (1.2)	0.027	0.97	<0.0001
Leisure walking (antilog min per week)	13.3 (1.1)	15.0 (1.1)	16.4 (1.1)	21.1 (1.1)	0.54	0.11	0.012
BMI	27.4 (0.33)	26.9 (0.33)	27.5 (0.33)	26.0 (0.33)	0.12	0.003	0.16
Physical QoL	52.6 (0.38)	53.4 (0.38)	52.0 (0.39)	53.3 (0.38)	0.48	0.006	0.36
Mental QoL	50.7 (0.44)	50.3 (0.45)	49.3 (0.46)	50.5 (0.45)	0.067	0.36	0.20
Neighborhood satisfaction	3.54 (0.10)	3.80 (0.10)	3.50 (0.10)	4.10 (0.10)	0.070	<0.0001	0.18
CES-D depression	9.25 (0.43)	8.91 (0.43)	10.27 (0.44)	9.07 (0.43)	0.28	0.079	0.17
Social cohesion	3.41 (0.07)	3.74 (0.07)	3.47 (0.07)	3.84 (0.07)	0.80	<0.0001	0.24
	Adjusted odds ratios (95% CI)						
% overweight or obese (≥ 25.0 BMI) (57.0% prevalence overall)	1.65 (1.21, 2.25) (63.1%)	1.53 (1.13, 2.07) (60.4%)	1.38 (1.24, 2.29) (56.8%)	1.00 (ref) (48.2%)	0.26	0.081	0.007
% obese (≥ 30.0 BMI) (21.3% prevalence overall)	1.86 (1.21, 2.85) (28.2%)	1.45 (0.95, 2.22) (19.6%)	1.83 (1.19, 2.81) (23.9%)	1.00 (ref) (14.2%)	0.23	0.007	0.22

Note: There were no interactions with site.

^a All models were adjusted for gender, age, education, ethnicity, # motor vehicles/adult in household, site, marital status, number of people in household, and length of time at current address. In addition, neighborhood clustering was adjusted for in all models. For MVPA, the IPAQ variables, BMI and overweight/obesity status, time was adjusted for to account for repeated measures.

perceived social cohesion than those in lower-income areas (3.79 vs. 3.44, respectively).

3.2.8. Percent overweight or obese (>25.0 BMI)

The walkability main effect was significant ($p = 0.007$), with the odds of being overweight or obese 35% higher for participants living in low- vs. high-walkability neighborhoods (OR = 1.35, 95% CI: 1.09, 1.69).

3.2.9. Percent obese (>30.0 BMI)

The income main effect was significant ($p = 0.007$), with participants living in lower-income neighborhoods having 53% greater odds of being obese than those living in higher-income neighborhoods (OR = 1.53, 95% CI: 1.12, 2.07).

3.3. Impact of neighborhood selection on neighborhood walkability and income effects

All analyses of outcome measures were repeated adding the “reasons for moving here” score as a covariate to control for preferences related to “activity-friendly” environments. Results in Table 4 show minor effects of the additional covariate on minutes of transport walking, minutes of leisure walking, mental QoL, and depression. For minutes of transport walking, the income-by-walkability interaction was no longer significant ($p = 0.11$). However, the walkability main effect was still highly significant ($p < 0.0001$). For minutes of leisure walking, the walkability main effect was no longer significant ($p = 0.36$). For mental QoL, the walkability main effect became significant ($p = 0.03$), with participants living in high-walkability neighborhoods having an average score that was slightly lower (49.7) than those living in low-walkability neighborhoods (50.7). For depression, the walkability main effect became significant ($p = 0.015$), with participants living in high-walkability neighborhoods having a higher score (9.88) than those in low-walkability neighborhoods (8.85).

4. Discussion

Four major findings emerged from the present study. First, neighborhood walkability was related to higher levels of physical activity and lower risk of being overweight or obese, but not to

social or psychological outcomes. Second, neighborhood income was not related to any measure of physical activity, but lower-income adults had less favorable weight status, physical QoL, neighborhood satisfaction, and social cohesion than higher-income participants. Third, there was only one significant interaction between neighborhood walkability and income, indicating walkability had a stronger positive association with walking for transport in high-income than in low-income participants. Fourth, after adjusting for potential self-selection bias (i.e., “reasons for moving here”), all significant associations of outcomes with walkability and income remained significant, except walking for leisure. However, associations with mental quality of life and depression score became significant, indicating slightly poorer mental health in residents of high-walkability neighborhoods, particularly for those in low-income areas.

Adults living in high-walkability neighborhoods had higher objectively measured total physical activity as well as higher self-reported walking for transportation and leisure than did participants from low-walkability neighborhoods. The weekly difference in objectively measured physical activity was about 47 min per week for the higher-income group and about 34 min for the lower-income group. On average, living in a high-walkability neighborhood was associated with meeting the 30 min per day physical activity guidelines (Haskell et al., 2007) at least one day more per week than those in low-walkability neighborhoods. Present findings confirm previous results of higher total physical activity in high-walkability neighborhoods (Frank et al., 2005; Saelens, Sallis, Black, & Chen, 2003). These results extend the evidence by demonstrating the effect generalizes to both higher- and lower-income groups, and the walkability effect appears to be stronger for objectively-measured than self-reported physical activity. Walkability associations with physical activity were not explained by self-selection into neighborhoods based on predisposition towards activity-friendly environments, a finding consistent with recent studies (Frank et al., 2007; Handy et al., 2006; Handy, Cao, & Mokhtarian, 2008). Non-significant differences in total physical activity by neighborhood income were unexpected, because higher activity levels among higher-income participants have been reported (Crespo et al., 2000; United States Department of Health and Human Services, 2000), but studies reporting SES differences in objectively measured physical activity

Table 4
Primary outcome results showing adjusted means by quadrant and tests of hypotheses for neighborhood income and walkability and the interaction adjusted for “reasons for moving here” scale.

Outcome	Adjusted means (SE) ^a				Tests of hypotheses (<i>p</i> -values)		
	Low-walkability/ low-income	Low-walkability/ high-income	High-walkability/ low-income	High-walkability/ high-income	Income × walkability interaction	Income main effect	Walkability main effect
Moderate-to-vigorous physical activity (min per day)	28.8 (1.5)	29.8 (1.5)	33.1 (1.5)	34.8 (1.5)	0.79	0.38	0.002
Transport walking (antilog min per week)	17.6 (1.2)	13.2 (1.2)	33.5 (1.2)	41.3 (1.2)	0.11	0.84	<0.0001
Leisure walking (antilog min per week)	14.2 (1.1)	17.0 (1.1)	15.8 (1.1)	18.4 (1.1)	0.92	0.13	0.36
BMI	27.4 (0.33)	26.9 (0.33)	27.5 (0.33)	26.0 (0.33)	0.14	0.003	0.23
Physical QoL	52.7 (0.37)	53.5 (0.39)	52.0 (0.39)	53.2 (0.39)	0.62	0.007	0.17
Mental QoL	50.8 (0.44)	50.6 (0.46)	49.2 (0.46)	50.2 (0.46)	0.16	0.41	0.030
Neighborhood satisfaction	3.56 (0.09)	3.84 (0.09)	3.48 (0.09)	4.04 (0.09)	0.12	<0.0001	0.49
CES-D depression	9.08 (0.41)	8.61 (0.43)	10.36 (0.43)	9.40 (0.43)	0.54	0.091	0.015
Social cohesion	3.43 (0.07)	3.78 (0.07)	3.46 (0.07)	3.79 (0.07)	0.88	<0.0001	0.81
	Adjusted odds ratios (95% CI)						
% overweight or obese (≥25.0 BMI)	1.62 (1.19, 2.22)	1.50 (1.10, 2.05)	1.37 (0.99, 1.87)	1.00 (ref)	0.29	0.086	0.011
% obese (≥30.0 BMI)	1.87 (1.21, 2.88)	1.47 (0.95, 2.27)	1.84 (1.20, 2.83)	1.00 (ref)	0.23	0.007	0.22

^a All models were adjusted for gender, age, education, ethnicity, # motor vehicles/adult in household, site, marital status, number of people in household, length of time at current address, and reasons for moving here. In addition, neighborhood clustering was adjusted for in all models. For MVPA, the IPAQ variables, BMI and overweight/obesity status, time was adjusted for to account for repeated measures.

are rare and generally agreed with present results (Troiano et al., 2008).

It appears walkability differences in walking for both transportation and leisure contributed to observed differences in total physical activity. It is well-established that adults walk more for transportation in walkable neighborhoods (Heath et al., 2006; Transportation Research Board and Institute of Medicine, 2005; Frank et al., 2004), but the few studies that examined leisure walking or total self-reported physical activity usually reported no walkability effect (Owen, Humpel, Leslie, Bauman, & Sallis, 2004; Saelens & Handy, 2008). The walkability–leisure walking association was weaker than the relation with transport walking, and after adjustment for self-selection, the walkability–leisure association became non-significant. This was expected because the walkability index was designed to explain transport walking.

There were no significant income differences on walking for transport or leisure, but there was an interaction between walkability and income on walking for transportation. The walkability–walking for transport association was weaker for adults living in lower-income than in higher-income neighborhoods. This is an important finding because it suggests lower-income residents may not experience all of the benefits from living in a walkable neighborhood unless other needs are met. Perceived danger from crime, which is higher among lower-income adults (Loukaitou-Sideris & Eck, 2007), could reduce their willingness to walk for transport even in high-walkability neighborhoods (Doyle, Kelly-Schwartz, Schlossberg, & Stockard, 2006). After adjusting for self-selection, the walkability by income interaction became non-significant. Self-selection may not apply equally to lower- and higher-income groups, since higher-income groups may be able to satisfy more personal criteria when selecting neighborhoods (Levine & Frank, 2007).

Previous studies found walkable neighborhoods protected against overweight and obesity (Papas et al., 2007), but the present study extends previous work. There was a highly significant walkability effect for percent overweight or obese. Though the walkability by income interactions were not significant, living in low-walkability neighborhoods was associated with about a 50% increased risk of being overweight or obese in the higher-income group (OR = 1.53), and the odds ratio was somewhat lower in the lower-income group (OR = 1.20). Adjusting for self-selection had virtually no effect on the odds ratios, raising questions about claims that the walkability–obesity association is due to self-selection (Handy et al., 2006; Frank et al., 2007; Eid et al., 2007).

Hypothesized QoL, social, and psychological benefits of living in walkable neighborhoods received no empirical support. Despite using high-quality measures and examining a variety of outcomes, there was no evidence residents of walkable neighborhoods had benefits beyond physical activity and weight status.

The negative finding of walkability in relation to mental health, after adjusting for neighborhood selection factors, is consistent with evidence linking high residential densities with psychological stress (Evans, 2003). However, scores on the present mental health measures were well within the normal range, so the practical impact of these small differences is unclear. A recent review reported some studies found built environment factors were related to depressive symptomatology, but the evidence base was small for any specific built environment characteristic, such as walkability (Mair, Diez Roux, & Galea, 2008; Clark, Stansfeld, & Candy, 2006). Results were inconsistent, with one study finding walkability was protective of depressive symptoms among older men, but not women (Berke et al., 2007). Neighborhood population density, a component of walkability, has been found previously to be positively, negatively, or not associated with mental health outcomes (Clark et al., 2006). The presence/absence or magnitude

of a built environment attribute may not be as important as its quality. For example, poorer quality of housing (e.g., state of repair) appears related to greater lifetime incidence of depression (Galea, Ahern, Rudenstine, Wallace, & Vlahov, 2005) and higher depressive symptomatology (Weich et al., 2002). More and better evidence is needed to improve understanding of built environment effects on mental health.

The present study confirmed the negative effects of low SES on multiple health outcomes. Lower-income participants had less favorable physical QoL, social cohesion, and neighborhood satisfaction. Unfortunately, there was little evidence that living in walkable neighborhoods alleviated these disadvantages, so efforts to improve social and physical environments, enhance health and social services, and empower vulnerable populations need to be strengthened. A recent study found walkable low-income, mostly-minority neighborhoods had lower levels of maintenance, aesthetic, and safety qualities than higher-income neighborhoods (Zhu & Lee, 2008), so neighborhood built environment attributes beyond walkability should be examined to determine their relation to health outcomes.

A strength of the present study was the design to recruit participants from two regions of the United States that differed in demographic composition, climate, geography, and era of development. Results generalized across the two regions. Other strengths included use of accelerometers to objectively assess physical activity, assessment of walking for multiple purposes, control for seasonal effects, selection of neighborhoods that varied widely on walkability defined by GIS and income, and use of validated measures. The present study is one of the few to statistically adjust for potential self-selection bias (Handy et al., 2006, 2008; Frank et al., 2007; Bagley & Mokhtarian, 2002).

An important limitation was the modest recruitment rate and the under-representation of racial-ethnic minority groups and very low SES participants. Thus, present findings should not be generalized to the most disadvantaged populations, and studies of very low-income and specific racial-ethnic populations are needed. The cross-sectional design is an important limitation, so prospective designs that follow people who move are needed to determine the relative contributions of personal and environmental influences on physical activity and weight status. Though the validity of the walkability index was supported in this study and several others, it has limitations related to the completeness and accuracy of the multiple data sets required for its computation. In addition, the intersection density variable, based on census block group geography, misses intersections at the boundaries of the blockgroup.

Physical inactivity and obesity are two of the most significant health problems in the United States and globally (Andersen, 2003; Dishman et al., 2004; World Health Organization, 2004), and both outcomes were related to neighborhood attributes which are directly controlled by public policies. Policies to encourage development of more walkable neighborhoods and enhancements to existing neighborhoods could provide health benefits to large proportions of the population, both low- and high-income, on a relatively permanent basis. Policies that favor walkable neighborhood designs have also been related to reductions in driving, greenhouse gases, and air pollution; conservation of open space; and reduced spending on public infrastructure (Frank et al., 2003, 2004, 2006; Ewing, Bartholomew, Winkelmann, Walters, & Chen, 2007). Some negative effects have been identified, such as local traffic congestion and concentration of air pollution (Frumkin et al., 2004). Thus, walkable neighborhoods are not a panacea, and policies promoting walkable development patterns should be combined with other policies to avoid negative outcomes, especially among low-income populations. The potential to produce widespread and long-lasting favorable impacts on physical activity

and overweight/obesity should make the creation and improvement of walkable neighborhoods a high priority on the public health agenda. An important next step in research is to identify the shape of the relation of neighborhood environment characteristics to physical activity and overweight/obesity outcomes so recommended levels of walkability attributes can be developed. Other studies are needed to strengthen evidence of causality through prospective and quasi-experimental studies.

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