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Associations of Neighborhood Environmental Attributes with Adults' Objectively-Assessed Sedentary Time: IPEN Adult Multi-Country Study

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Abstract

Neighborhood environmental attributes have been found to be associated with residents' time spent walking and in physical activity, in studies from single countries and in multiple-country investigations. There are, however, mixed findings on such environmental relationships with sedentary (sitting) time, which primarily have used evidence derived from single-country investigations with self-reported behavioral outcome measures. We examined potential relationships of neighborhood environmental attributes with objectively-assessed sedentary time using data from 5,712 adults recruited from higher and lower socio-economic status neighborhoods in 12 sites in 10 countries, between 2002 and 2011. Ten perceived neighborhood attributes, derived from an internationally-validated scale, were assessed by questionnaire. Sedentary time was derived from hip-worn accelerometer data. Associations of individual environmental attributes and a composite environmental index with sedentary time were estimated using generalized additive mixed models. In fully adjusted models, higher street connectivity was significantly related to lower sedentary time. Residential density, pedestrian infrastructure and safety, and lack of barriers to walking were related to higher sedentary time. Aesthetics and safety from crime were related to less sedentary time in women only. The predicted difference in sedentary time between those with the minimum versus maximum composite environmental index values was 71 min/day. Overall, certain built environment attributes, including street connectivity, land use mix and aesthetics were found to be related to sedentary behavior in both expected and unexpected directions. Further research using context-specific measures of sedentary time is required to improve understanding of the potential role of built environment characteristics as influences on adults' sedentary behavior.

Key words: built environment, sedentary behavior, adults, sitting time

INTRODUCTION

High volumes of sedentary (sitting) time can be associated – after accounting for moderate-to-vigorous activity – with premature mortality and other health problems (1, 2). Adults can spend a majority of their waking hours sitting (3, 4). Recent evidence indicates that the greatest risk of mortality from sitting time is among adults who are in the top sedentary quartile but who are also physically inactive (5).

If broad-based changes in sedentary time are to be pursued, environmental and policy initiatives will be required (6, 7). Similar to associations observed between aspects of the built environment and physical activity (6), sedentary behavior may be influenced by surrounding environmental conditions. It is possible, for example, that neighborhood environments that are unsafe, or have low walkability, may lead to less leisure-time physical activity and thus more time spent in TV viewing and other sedentary indoor engagements. For example, aesthetics have been found to be associated with lower levels of sedentary time (8), while higher levels of perceived safety and the presence of street lighting have been associated with lower levels of TV viewing among Belgian (9) and Hong Kong older adults (10). Evidence for associations with walkability characteristics is more mixed. Some studies have found walkability features, including residential density, to be associated with higher levels of sedentary time (8, 11), while others have observed associations with lower levels of TV viewing time amongst women (12).

Some of these associations may be gender-specific – two studies have found neighborhood aesthetics (13) and perceptions of safety concerns (8, 13) to be associated with higher levels of TV viewing and overall sitting time among women only. Similarly, research from Australia has found that residential density and access to transit stops were associated with less sitting time, but only for women (14).

While there is some evidence suggesting potential associations between perceptions of the built environment and sitting time, a recent review concluded that the pattern of associations within the published studies was modest and inconsistent (15). In addition, some more recent studies assessing associations between objective measures of the environment and sedentary time have failed to identify significant associations (16-18). The inconsistent relationships between environmental attributes and sedentary behavior may be because such relationships are less direct and strong than are those for physical activity. It is also possible that non-significant or weak associations reported in single-country studies may be due partly to limited variation in environmental attributes. With the exception of two multi-country studies (8, 16), the evidence on perceived environmental correlates of sedentary behaviors arises from single countries. Studies involving multiple countries can fill this gap by providing broader environmental variance (19). Previous literature has also often employed self-report measures of sedentary time (15), which often have poor accuracy and precision (20). Research employing objective measures of sedentary time potentially can provide more robust evidence on environmental correlates (21).

The primary aim of the present study was to identify potential associations of perceived neighborhood environmental attributes with accelerometer-derived overall sedentary time across 10 countries. To assess variation between countries, we examined overall and site-specific associations. Gender-specific associations were also assessed based on previous research suggesting possible gender differences (12-14). In light of some inconsistent associations between environmental attributes and sitting time in previous studies (15), we hypothesised that positive perceptions of neighborhood environmental attributes supporting physical would be negatively associated with sedentary time.

METHODS

Study design

The IPEN (International Physical Activity and the Environment Network) Adult study is an observational, epidemiologic, multi-country, cross-sectional study, including 17 city-regions (hereafter, ‘sites’) located within 12 countries worldwide: Australia (Adelaide), Belgium (Ghent), Brazil (Curitiba), Colombia (Bogota), Czech Republic (Olomouc, Hradec Kralove), Denmark (Aarhus), China (Hong Kong), Mexico (Cuernavaca), New Zealand (North Shore, Waitakere, Wellington, Christchurch), Spain (Pamplona), the United Kingdom (Stoke-on-Trent) and the United States (Seattle, Baltimore). For the present analyses, data were included from 12 sites in 10 countries (excluding Australia and New Zealand) that used ActiGraph accelerometers.

Study participants were recruited from neighborhoods chosen to maximize variance in neighborhood walkability and income. For selection of neighborhoods, all countries but one (Spain) used a neighborhood walkability index that was measured objectively with Geographic Information Systems (GIS) data at the smallest administrative unit available. The neighborhood-selection techniques employed in each country can be found elsewhere (22). For every administrative unit across study sites, the walkability index was derived as a function of at least two of the following variables: net residential density, land use mix and intersection density. In four countries, retail floor area ratio was also included in the index as a proxy for pedestrian-oriented design. The walkability index is described in more detail elsewhere (23, 24). In each country, administrative units were ranked based on the walkability index and household-level income data from the census; the selection procedure resulted in an equal number of neighborhoods among four pre-specified types (quadrants), stratified as follows: high-walkable/high-income, high-walkable/low-income, low-walkable/high-income, and low-walkable/low-income.

Participant recruitment

IPEN used a systematic strategy to recruit participants. Random samples of adults (aged between 18 and 66 years) living in the selected neighborhoods were contacted and invited to wear an accelerometer for objective physical activity assessment. Three countries recruited and conducted data collection by phone and mail/online surveys and six countries visited participants in person to deliver study materials. In Hong Kong, intercept interviews were conducted in residential areas where individual addresses were not available (e.g., high-rise apartments). Study dates ranged from 2002 to 2011. Further details on the participant recruitment techniques and response rates across countries can be found elsewhere (22).

Of the 9,065 potential participants, 3,100 were not part of the accelerometer subsample per country or had missing accelerometer data and 253 had less than four valid (at least 10 wearing hours) days of data, yielding a final sample of 5,712. Compared to potential participants who were excluded, those with valid accelerometer data were more likely to be older ($p<.001$), married or in a defacto relationship ($p<.001$), employed ($p=.014$), and living in neighborhoods perceived to have higher levels of safety from crime ($p=.037$). The socio-demographic characteristics of the sample with valid accelerometer data, by study site, are presented in Table 1.

Quality control

All country investigators completed San Diego State University Institutional Review Board training, and met the NIH Fogarty International Center and their own country's ethics requirements. All study participants provided informed consent for participation in their country-level study and all countries obtained ethical approval from their relevant ethics committees. Participant confidentiality for pooled data was maintained by de-identification using numeric identification codes. For data transfer, a secure file sharing system was used. Survey data were assessed for completeness by the study sites and double-checked by the central IPEN coordinating center. Accelerometer data were provided in pre-processed format (i.e. DAT or CSV files) to the central IPEN coordinating center. Trained researchers at the coordinating center screened and scored all data using MeterPlus software version 4.3. (www.meterplussoftware.com). Protocols for screening data were developed for different accelerometer models, methods of deployment, available documentation of wearing time, and cultural differences in activity patterns (25).

Measures

Neighborhood Environment Walkability Scale (NEWS)

The NEWS assesses perceived neighborhood attributes related to walking (26, 27), but has also been found to be related to sedentary behavior (8). Because the IPEN Adult study is an aggregate of studies conducted at different times (some with data collection completed prior to joining the IPEN study), the NEWS items collected across countries were not all identical. To maximize the number of participating countries and participant sample sizes, previous validation work compared the NEWS/NEWS-A items used in each country and confirmed scales could be constructed that were comparable across the 12 IPEN countries (19). The resulting 10 NEWS measures constructed for the IPEN Adult study gauge the following perceived neighborhood attributes: (1) Residential density; (2) Land use mix–diversity; (3) Land use mix–access; (4) Street connectivity; (5) Infrastructure and safety for walking; (6) Aesthetics; (7) Traffic safety; (8) Safety from crime; (9) Streets having few cul-de-sacs; and (10) No physical barriers to walking.

The *Residential density* subscale is a weighted sum of items reflecting perceived presence of dominant housing types, ranging from predominantly single-family dwellings to high-rise buildings with more than 20 stories. *Land use mix–diversity* reflects average perceived walking proximity (i.e., average of five-point ratings ranging from ≤5 minute walk to 30+ minute walk) from home to nine types of destinations: supermarket, small grocery or similar stores, post office, any school, transit stop, any restaurant, park, gym or fitness facility, and other stores and services. The remaining eight scales are average ratings of items answered on a four-point Likert scale (1= strongly disagree to 4 = strongly agree). Scales were scored in a direction consistent with higher walkability and safety, with individual items reversed when necessary. Exact items and scoring for each country's scales are provided in detail in Cerin et al. (19).

Objectively-assessed sedentary time (main outcome) and physical activity (covariate)

Total minutes/day of sedentary time and total minutes/day of moderate-to-vigorous intensity physical activity (MVPA) were derived using accelerometer data. Reliability and validity properties of accelerometers have been documented extensively (28, 29). In three countries accelerometers were mailed to participants and in others they were hand-delivered and retrieved. Participants were asked to wear the accelerometer above the right hip for seven consecutive days during waking hours and to remove it only for water activities (e.g. swimming, bathing).

Participating countries employed different ActiGraph accelerometer models including the 7164, 71256, GT1M, ActiTrainer and GT3X models (Pensacola FL) (30). The accelerometer data were collected in (or aggregated to) one-minute epochs using a common software program (MeterPlus version 4.3). Counts per minute from the vertical axis were converted into estimated minutes of sedentary time (≤100 counts/min), moderate- (1952-5724 counts/min), and vigorous-intensity (5725+ counts/min) physical activity (31).

Socio-demographic characteristics

Age, gender, educational level and marital status of the participants were assessed and included as covariates in all statistical models. While types of education varied by country, all country data could be categorized into 'having university degree', 'having high school diploma' and 'having less than high school diploma'. Marital status was dichotomized into living with a partner/spouse versus not living with a partner/spouse. Employment status was determined by asking participants if they currently have a job or do unpaid work outside the home; responses were recorded as yes or no to this item.

Data analyses

Descriptive statistics were computed for the whole sample and by study site. Associations of perceived environmental attributes with objectively-measured sedentary time were estimated using generalized additive mixed models (GAMMs). GAMMs can model data following various distributional assumptions, account for dependency in error terms due to clustering (participants recruited from selected administrative units), and estimate complex, dose-response relationships of unknown form (32). Preliminary analyses based on residuals and Akaike's Information Criterion (AIC, a measure of model fit) indicated that GAMMs with Gaussian variance and identity link functions would be most appropriate to model objectively-measured sedentary time.

Main-effect GAMMs estimated the dose-response relationships of perceived environmental attributes with objectively-measured sedentary time, adjusting for study site, socio-demographic covariates, objectively-measured MVPA, accelerometer wear time and area-level socio-economic status. We estimated separate covariate-adjusted GAMMs for each environmental attribute (single environmental-attribute models) and for all environmental attributes entered in the model simultaneously (multiple environmental-attribute models).

A composite environmental index was constructed by summing up the standardized scores (z-scores) of the environmental attributes that were positively related, and subtracting the standardized scores of variables that were negatively related, to sedentary time (in any of the GAMMs). GAMMs with the composite environmental index as a predictor of sedentary time were estimated.

Curvilinear relationships were estimated using non-parametric smooth terms in GAMMs, which were modeled using thin-plate splines (32). Smooth terms failing to provide sufficient evidence of a curvilinear relationship (based on AIC) were replaced by simpler linear terms. Separate GAMMs were run to estimate sedentary time by study site and by gender interaction effects (two-way and three-way interactions). The significance of interaction effects was evaluated by comparing AIC values of models with and without a specific interaction term. An interaction effect was deemed significant if it yielded a >2-unit smaller AIC than the main effect model (33). Significant interaction effects were probed by computing the site- and/or gender-specific association.

Fewer than 5% of cases (4.5%; n=256) had missing data. Thus, analyses were performed on complete cases (34). Participants with missing data were more likely to be women (p=.021), have fewer valid hours (p=.003) and days (p=.027) of accelerometer wear time, report lower perceived neighborhood aesthetics (p=.004), and be less likely to hold a tertiary degree (p=.025). All analyses were conducted in R using the packages ‘car’ (35), ‘mgcv’ (32) and ‘gmodels’ (36).

RESULTS

Table 1 shows sample characteristics and overall and site-specific sample characteristics, including average daily objectively-assessed sedentary time. Mean sedentary time of all sites was 8.5 hours/day (59% of accelerometer wearing time), ranging from 7.7 hours/day in Bogota (Colombia, 56% of wear time) to 9.5 hours/day in Aarhus (Denmark, 64% of wear time). Cuernavaca (Mexico) and Curitiba (Brazil) had lower levels of sedentary time than the average, while Pamplona (Spain), Hong Kong (China), and Baltimore (USA) had higher than average amounts of sedentary time. Table 2 shows the overall and site-specific mean values and standard deviations for the perceived environmental attributes.

Table 1. Overall and site-specific sample characteristics

	ALL SITES	BEL	BRA	COL	CZE		DEN	HK	MEX	ESP	UK	USA	
					Site A	Site B						Site C	Site D
Overall N[1]	5712	1050	330	223	258	122	272	269	656	329	135	1198	870
Age, mean (SD)	43 (12)	43 (13)	42 (13)	46 (12)	39 (14)	36 (14)	40 (14)	42 (13)	42 (13)	39 (13)	44 (13)	44 (11)	47 (11)
Gender, *%men*	47	48	48	32	36	39	39	41	46	40	47	55	49
Education													
%Less than HS	14	4	28	47	23	16	7	36	44	4	39	1	2
%HS graduate	33	33	31	36	43	57	42	23	29	33	46	35	30
%College or more	52	63	41	17	33	28	50	41	27	63	15	64	69
Work status, *%working*	77	80	79	61	78	83	75	63	71	76	64	81	83
Marital Status, *%couple*	63	73	60	61	60	53	69	56	65	57	46	64	61
BMI, mean (SD)	25.7 (4.9)	24.2 (3.9)	26.2 (4.3)	25.5 (4.1)	24.6 (3.9)	24.2 (3.6)	24.2 (4.0)	22.6 (3.4)	28.0 (5.0)	23.9 (3.4)	27.2 (5.1)	26.6 (5.4)	27.2 (5.7)
Accelerometer wear time, valid days (SD)	6.5 (1.1)	6.7 (1.1)	6.7 (1.0)	6.6 (1.0)	6.2 (1.2)	6.2 (1.4)	7.0 (0.8)	5.9 (1.0)	5.7 (1.0)	6.5 (0.8)	6.6 (1.0)	6.7 (0.8)	6.7 (1.2)
Accelerometer wear time, hr/day (SD)	14.5 (1.3)	14.7 (1.3)	14.0 (1.3)	13.9 (1.2)	13.9 (1.4)	14.2 (1.3)	14.9 (1.1)	14.4 (1.4)	14.0 (1.4)	15.0 (1.1)	14.6 (1.2)	14.7 (1.3)	14.8 (1.4)
Sedentary time, min/day (SD)	512.9 (105.1)	507.1 (109.8)	475.6 (111.5)	462.9 (92.2)	486.5 (101.3)	508.1 (95.0)	571.8 (90.5)	542.4 (97.8)	467.8 (89.8)	543.8 (87.7)	499.1 (104.4)	523.5 (103.7)	537.5 (102.2)
MVPA time, min/day (SD)	36.3 (25.4)	35.5 (23.5)	31.5 (24.6)	37.0 (26.4)	47.1 (27.7)	45.1 (25.9)	39.7 (23.3)	44.9 (25.3)	31.2 (25.2)	51.0 (29.5)	36.7 (27.3)	36.3 (24.9)	29.2 (22.0)

Notes: [1] N for some variables is reduced due to missing data. Site A: Olomouc, B: Hradec Kralove, C: Seattle, D: Baltimore. Accelerometer wear time, valid days = total number of valid days of 10+ wearing hours. Accelerometer wear time, hr/day= average number of valid hours per valid day. Sedentary time, min/day= average minutes of sedentary per valid day. Moderate-vigorous physical activity (MVPA) time, min/day= average minutes of moderate-to-vigorous physical activity per valid day. Missing values: age (0.2%), gender (0%), education (1%), work status (0.2%), marital status (1%), BMI (0.9%)

Table 2. Overall and site-specific perceived-environment scores

	All SITES	BEL	BRA	COL	CZ		DEN	HK	MEX	ESP	UK	USA	
					Site A	Site B						Site C	Site D
Overall N[1]	5712	1050	330	223	258	122	272	269	656	329	135	1198	870
Residential density (SD)	86.9 (122)	82.6 (72.4)	99.7 (123.6)	51.7 (59.6)	89.1 (68.6)	85.1 (68.8)	83.5 (63.4)	443.8 (216.2)	38.1 (40.9)	187.0 (102.3)	36.2 (32.5)	37.5 (53.9)	59.9 (79.4)
Land use mix-Access (SD)	3.3 (0.7)	3.3 (0.6)	3.6 (0.5)	3.4 (0.4)	3.5 (0.6)	3.4 (0.6)	3.6 (0.6)	3.5 (0.7)	3.3 (0.5)	3.7 (0.5)	3.4 (0.7)	3.2 (0.8)	3.0 (0.8)
Connectivity (SD)	3.0 (0.7)	2.7 (0.7)	3.3 (0.7)	3.1 (0.6)	3.0 (0.7)	3.0 (0.6)	3.1 (0.6)	3.2 (0.8)	2.9 (0.5)	3.3 (0.7)	3.1 (0.7)	3.0 (0.8)	3.0 (0.8)
Infrastructure and safety (SD)	3.0 (0.6)	2.8 (0.5)	2.8 (0.8)	2.8 (0.5)	3.1 (0.5)	3.2 (0.5)	3.1 (0.5)	3.4 (0.6)	2.6 (0.4)	3.4 (0.5)	3.2 (0.5)	3.0 (0.6)	3.1 (0.6)
Aesthetics (SD)	2.8 (0.7)	2.6 (0.6)	2.9 (0.8)	2.4 (0.5)	2.4 (0.6)	2.6 (0.5)	2.7 (0.6)	2.8 (0.7)	2.6 (0.5)	2.7 (0.7)	2.3 (0.8)	3.1 (0.7)	3.1 (0.6)
Safety from traffic (SD)	2.6 (0.7)	2.4 (0.6)	2.4 (0.8)	2.4 (0.5)	2.9 (0.6)	3.1 (0.5)	2.9 (0.5)	2.9 (0.6)	2.4 (0.5)	2.5 (0.7)	2.5 (0.7)	2.7 (0.7)	2.7 (0.7)
Safety from crime (SD)	3.1 (0.8)	3.2 (0.5)	2.3 (0.5)	1.9 (0.6)	3.2 (0.6)	3.4 (0.5)	3.3 (0.6)	3.4 (0.70	2.2 (0.7)	3.6 (0.6)	3.0 (0.7)	3.4 (0.6)	3.4 (0.7)
Few cul-de-sacs (SD)	2.9 (1.0)	3.0 (0.8)	2.9 (1.1)	2.7 (0.8)	2.9 (1.0)	3.0 (0.9)	2.8 (0.9)	3.5 (0.8)	2.6 (0.7)	3.6 (0.9)	2.3 (1.0)	2.8 (1.1)	2.8 (1.2)
No major barriers (SD)	3.3 (0.9)	3.3 (0.7)	3.1 (1.1)	2.9 (0.7)	3.4 (0.8)	3.5 (0.8)	3.7 (0.6)	3.3 (1.0)	2.8 (0.7)	3.6 (0.8)	3.4 (0.8)	3.2 (1.0)	3.8 (0.6)
Land use mix - diversity (SD)	3.8 (0.8)	3.6 (0.9)	4.1 (0.5)	4.2 (0.4)	3.9 (0.6)	4.0 (0.6)	4.2 (0.6)	4.1 (0.7)	3.7 (0.6)	4.5 (0.4)	3.7 (0.5)	3.8 (0.8)	3.6 (0.9)
Composite index of sedentariness (SD)	0.0 (2.6)	0.0 (2.6)	-0.6 (2.6)	-0.2 (1.5)	1.2 (1.9)	1.2 (1.9)	1.2 (1.9)	3.8 (3.1)	-1.4 (1.7)	2.5 (2.1)	0.7 (2.0)	-1.0 (2.2)	-0.3 (2.1)

Notes: [1] N for some variables is reduced due to missing data. Site A: Olomouc, B: Hradec Kralove, C: Seattle, D: Baltimore. Land use mix-Diversity = Land Use Mix-Diversity: Proximity to 9 places-categories. Missing values: Residential density (2.2%), Land use mix-Access (0.7%), Connectivity (0.8%), Infrastructure and safety (0.8%), Aesthetics (0.8%), Safety from traffic (0.8%), Safety from crime (0.8%), Few cul-de-sacs (0.8%), No major barriers (0.8%), Land use mix - diversity (0.6%). Composite index of sedentariness (2.2%).

Associations of specific environmental attributes with sedentary time

Associations of perceived environmental attributes with objectively-measured sedentary time did not significantly differ by study site, therefore only the combined results are presented. The single environmental-variable models identified five significant environmental correlates of sedentary time (Table 3). Higher residential density, pedestrian infrastructure and safety and lack of barriers to walking were related to higher sedentary time. Aesthetics and safety from crime were related to less sedentary time in women only. In contrast, few cul-de-sacs, land use – access, land use – diversity, connectivity and traffic safety were not significantly associated with sedentary time.

In the multiple-environmental variable model, all of those environmental correlates remained statistically significant with the exception of safety from crime. Additionally, after adjustment for other perceived environmental correlates, higher street connectivity was found to be associated with lower levels of sedentary time, while land use mix–diversity was found to be related to less sedentary time in men only (Table 3).

Table 3. Pooled associations of perceived environmental attributes with objectively-measured sedentary time (average daily minutes)

Environmental attribute	Effect	Single-environmental-attribute models			Multiple-environmental-attribute models		
		b	95% CI	p	b	95% CI	p
Residential density	Main	0.078	0.053, 0.105	<.001	0.075	0.048, 0.102	<.001
Land use mix –access	Main	3.029	-0.301, 6.342	.08	1.156	-2.747, 5.059	.56
Land use mix – diversity	Main	1.588	-1.532, 4.709	.32	-1.593	-5.169, 1.983	.38
	Men-specific	-	-	-	-5.293	-9.839, -0.747	.02
	Women-specific	-	-	-	1.662	-2.641, 5.965	.45
Connectivity	Main	1.925	-4.963, 1.113	.22	-4.719	-8.051, -1.467	<.01
Pedestrian infrastructure and safety	Main	8.287	4.464, 12.109	<.001	8.300	4.026, 12.575	<.001
Aesthetics	Main	-3.316	-6.844, 0.211	.07	-4.294	-7.915, -0.672	.02
	Men-specific	2.765	-2.066, 7.595	.26	2.129	-2.748, 7.005	.39
	Women-specific	-7.936	-12.268, -3.604	<.001	-9.127	-13.535, -4.719	<.001
Traffic safety	Main	1.873	-1.431, 5.178	.27	2.507	-0.986, 6.000	.16
Safety from crime	Main	-0.171	-3.798, 3.455	.93	0.144	-3.600, 3.888	.94
	Men-specific	4.281	-0.370, 8.932	.07	-	-	-
	Women-specific	-3.782	-8.608, -0.044	<.05	-	-	-
Few cul-de-sacs	Main	1.563	-0.698, 3.824	.17	1.471	-0.785, 3.728	.20
No major barriers to walking	Main	3.561	0.947, 6.174	<.01	2.928	0.236, 5.620	.03
Composite environmental index	Main	3.354	2.363, 4.345	<.001	-	-	-
	Men-specific	1.990	0.663, 3.318	<.01	-	-	-
	Women-specific	4.483	3.255, 5.711	<.001	-	-	-

b = regression coefficient; 95% CI = 95% confidence intervals; p = p value; - = not applicable. All regression coefficients are adjusted for respondents' age, sex, marital status, educational attainment, employment status, administrative-unit socio-economic status, average objectively-measured min/day of moderate-to-vigorous physical activity and accelerometer wear time. For environmental attributes with significant gender moderating effects, gender-specific associations (men- and women-specific) are reported.

Associations of a composite environmental index with sedentary time

The attributes found to be significant in the multiple-environmental model (perceived residential density, pedestrian infrastructure and safety, no major barriers to walking, land use mix–diversity, street connectivity, aesthetics, and safety from crime) were used to derive a composite environmental index based on the sum of the standardized values (z-scores) of each variable, as detailed in the Methods section. This index was positively related to objectively-assessed sedentary time (Table 3). Each additional unit on the index was associated with 3.4 min/day more sedentary time. The association was stronger in women than in men (Table 3), with women showing 4.5 more min/day and men 2.0 more min/day of sedentary time for each one-unit increment in the composite environmental index. The predicted difference in sedentary time between those with the minimum (-9.2) and maximum (11.6) values on the composite environmental index was 71 min/day of sedentary time.

DISCUSSION

Across all 10 countries, on average adults spent 59% of waking hours spent sedentary, ranging from 56% (Colombia and Mexico) to 64% (Denmark). The difference in average sedentary time between the least and most sedentary countries was nearly 110 min/day, reflecting a wide range of variation in sedentary time. However, interestingly there were no significant differences in associations between perceived environment attributes and sedentary time across study sites, suggesting these findings may be generalizable across multiple countries.

The combined findings with individual environmental attributes showed both expected and unexpected associations. Interpretation is challenging, not the least because sedentary behaviors take place both within and outside of neighborhood environments. Those living in areas with higher connectivity or with better aesthetics (women only) had less sedentary time. Street connectivity is a key component of walkability measures and is associated with higher levels of walking for transport (37). Thus it was hypothesised that it may lead to lower levels of sedentary behavior. Aesthetics have previously been found to be positively associated with recreational walking (38). Residents in areas perceived to be aesthetically pleasing may spend less time in sedentary pursuits at home and more time outdoors in active leisure pursuits. These findings also align with other studies suggesting stronger associations between perceptions of aesthetics and safety from crime and sedentary behavior amongst women (8, 13).

Interestingly, two destination-related measures (land use mix–diversity and land use mix–access), which are often associated with walking, were not related to sedentary time (except for diversity with men's sedentary time). In addition, reporting higher levels of pedestrian infrastructure and safety and having no major barriers to walking were associated with higher levels of sedentary time. Of note, other analyses using data from the IPEN study have not found pedestrian infrastructure and safety and barriers to walking to be associated with either self-reported walking for transport or recreation (38). In general, literature on associations between neighborhood walkability and sedentary time are mixed (8, 11, 12, 39). Differences in population characteristics or walkability and/or sedentary behavior measures may explain some of this variation.

Another somewhat unexpected finding was that higher residential density was associated with more sedentary time. Given that higher residential density is typically associated with higher levels of physical activity (30, 40), it was anticipated that density would be negatively associated with sedentary time. One previous study (41) has found higher levels of leisure-time sitting amongst those in smaller dwellings and apartments, which could be an explanation for this finding. In higher density areas smaller house sizes may provide fewer opportunities for incidental light intensity activity compared to larger dwellings, encouraging more time spent sitting. Another possibility is that residents of higher density areas may spend larger amounts of time sitting for work outside of the neighborhood environment (42). However, as analyses adjusted for employment status, educational attainment and area-level socio-economic status, this would appear unlikely.

Overall, the difference in sedentary time between the sites with the lowest and highest values on the composite environmental index was around 70 min/day, which is equivalent to 14% of the mean sedentary time of this study sample. Given that interventions to reduce sedentary behavior achieve reductions in sitting of less than 80 minutes per day (43, 44), this suggests that meaningful behavioral change may be possible if efforts are focused on improving the neighborhood built environment. However, given the unexpected findings described above, further knowledge is needed about the specific environmental attributes that should be targeted to inform the nature of environmental interventions.

Further research examining associations between environmental features and domain-specific sedentary behaviors—for example, work, leisure and transport sitting—is needed to explain these diverging findings. Correlations between sedentary behavior and moderate-vigorous physical activity (e.g. walking) have often been found to be quite low (45). For this reason, it may not be appropriate to assume inverse associations with all walkability features. It is possible that the amount of time that people spend in sedentary behavior and light intensity physical activity (the behavior sitting time generally replaces), may be more influenced by micro environments, such as the availability of television sets and computers in the home (46, 47), or office furniture within the workplace (48).

Strengths of this study include the large, multi-country study design, and the objective measurement of sedentary behavior. However, although accelerometers are objective in that they do not rely on self-reports, there are some limitations. Most importantly, accelerometers do not assess position, so while accelerometer-measured "sedentary time" examined here is based on widely-accepted cut-points (as described above in the Methods section) it nevertheless will include an unknown mix of sitting, standing, and lying. In addition, although laboratory studies have demonstrated comparability between ActiGraph models for moderate-to-vigorous physical activity (49-51), there have been differences reported between the 7164 and the newer generation models (i.e., GT1M/GT3X) in lower intensity movement (52, 53). Participants using the 7164 model may have recorded fewer minutes of sedentary time, although the only country to exclusively use the 7164 was the USA. The low frequency extension has been shown to attenuate these differences (52, 53) but was not available for this study due to the timing of data collection.

Our mixed findings also highlight the limitation of not being able to examine the specific correspondence between the contexts in which sedentary behaviors take place (particularly domestic and workplace environments) and the neighborhood environments to which our exposure measures related. Differences in the composition of total sedentary time in our sample (e.g. the relative contribution of work and leisure-related sitting) may explain some of these findings. For example, working adults can accumulate the majority of daily sitting time in the workplace setting (54), thus built environments around participants' home may be a weaker correlate of total sedentary behaviour for this population group. For intervention purposes, it is important for further research to assess whether neighborhood environmental attributes are more strongly associated with specific sedentary behaviors such as driving or TV time. Although non-workers were less than a quarter of the overall study sample, they are a subgroup who may spend longer time in their neighborhoods and thus display a stronger correspondence between neighborhood environment attributes and their sedentary time. To provide more targeted evidence for particular environmental and urban design policy initiatives, the separation of sedentary time measures into domain-specific components would be highly informative. The use of wearable cameras may be helpful in providing more contextual information to supplement accelerometer measures of sedentary time in future research (55)(48).

The environmental attributes were assessed using a previously developed self-report instrument with known measurement properties (19, 26, 27). Some recent research using objectively-assessed measures of the built environment has failed to observe significant associations with accelerometer-assessed sedentary time (16, 18). Further comparative research is needed to determine whether differential associations are observed between perceptions and objectively-assessed built environment features with sedentary behaviors.

In conclusion, in this large multi-country study, we identified street connectivity, land use mix and aesthetics—built environment attributes found to be positively related to physical activity—to be associated with lower adult sedentary time. Unexpectedly, other environmental attributes considered important for walking, including residential density, pedestrian infrastructure and no barriers to walking, were associated with more sedentary time. Future research should assess context-specific measures of sedentary time, to improve understanding of how features of the environment may influence particular sedentary behaviors. This knowledge would provide more targeted evidence for environmental and urban design policy initiatives aimed at promoting sitting less and moving more.

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Conflicts of Interest

The authors declare no conflicts of interest

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CONFLICTS OF INTEREST

'Conflicts of interest: none'.

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Highlights

- Adults' levels of sedentary time are high and vary widely by country and city.
- In 12 cities, sedentary time ranged from 7.7 hrs/day in Bogota to 9.5 in Aarhus.
- Higher street connectivity was associated with lower levels of sedentary time.
- Residential density and walking infrastructure related to higher sedentary time.