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Built Environment, Physical Activity, and Obesity: Findings from the International Physical Activity and Environment Network (IPEN) Adult Study

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Abstract

Creating more physical activity–supportive built environments is recommended by the World Health Organization for controlling noncommunicable diseases. The IPEN (International Physical Activity and Environment Network) Adult Study was undertaken to provide international evidence on associations of built environments with physical activity and weight status in 12 countries on 5 continents (n > 14,000). This article presents reanalyzed data from eight primary papers to identify patterns of findings across studies. Neighborhood environment attributes, whether measured objectively or by self-report, were strongly related to all physical activity outcomes (accelerometer-assessed total physical activity, reported walking for transport and leisure) and meaningfully related to overweight/obesity. Multivariable indexes of built environment variables were more strongly related to most outcomes than were single-environment variables. Designing activity-supportive built environments should be a higher international health priority. Results provide evidence in support of global initiatives to increase physical activity and control noncommunicable diseases while achieving sustainable development goals.

INTRODUCTION

The United Nations identified noncommunicable diseases (NCDs) as threats to international health, quality of life, and economic development (80). The Global Action Plan for the Prevention and Control of NCDs identified physical inactivity as a priority intervention target (88). An estimated 5.3 million deaths annually worldwide can be attributed to physical inactivity through its effects on cardiovascular diseases, some cancers, and diabetes (48). In the United States, physical inactivity contributes to about 175,000 deaths per year (25) and is responsible for about 10% of total medical care costs (13). With ever-growing evidence of numerous beneficial effects of physical activity on NCDs, brain health, psychological health, and quality of life (55), in combination with the persistently high prevalence of physical inactivity worldwide (41, 63), the pandemic of physical inactivity can be considered one of the major public health challenges of the twenty-first century (47).

In the latter decades of the twentieth century, physical activity promotion approaches typically targeted leisure-time activities, were guided by psychologically based theories, and were designed to educate and motivate individuals to apply self-regulation skills to manage their own physical activity (65). Despite significant results in many studies, the approach was seen by many as insufficient for changing physical activity in populations. Programs were not widely disseminated, participation was generally low, changes were modest, and maintenance of change was a continuing problem (65). Together, these limitations denote a low scalability potential for these approaches (60). Near the beginning of the twenty-first century, approaches to physical activity research and intervention evolved. First, new conceptualizations were based on the idea that, throughout human history, physical activity was integrated into many aspects of daily life. New measures, such as the International Physical Activity Questionnaire (24), assessed physical activity for multiple purposes or domains: leisure, transport, occupational (or school), and household. Second, broader multilevel ecological models were applied to physical activity, emphasizing the likely influences of organizations, built environments, and policies in multiple sectors that should be considered in addition to more widely studied individual factors (68). Ecological models were developed that proposed multiple levels of influence for each domain of physical activity (65). Third, new areas of interdisciplinary research were initiated to investigate built environment and policy correlates and determinants of physical activity. Collaborations between public health and exercise science investigators and professionals with expertise in built environments such as urban planning, transportation planning, and parks and recreation became more common. The explicit goal of these collaborations was to generate and transfer knowledge to guide environment and policy interventions in multiple settings across sectors with the potential to permanently increase physical activity in populations worldwide (66, 67).

Rapid progress has been made in identifying the built environment variables that play roles in physical activity, such as walkable neighborhood designs, access to parks, availability of public transit, and quality of pedestrian and bicycling infrastructure (35, 39, 79). Reviews indicated that most studies had been conducted in a small number of countries in North America, Europe, and Australasia (27), yet most deaths attributable to physical inactivity occur in low- and middle-income countries that make up most of the world's population (48, 87). It was difficult to compare results across countries owing to methodological differences (27). Thus, it was unknown to what extent associations were similar or different across countries.

The International Physical Activity and Environment Network (IPEN; **http://www.ipenproject.org**) was formed to expand the range of countries conducting built environment studies. IPEN was launched in 2004 to encourage built environment research in many countries, promote the use of comparable study designs and measures, coordinate international studies, and communicate results to decision makers in multiple sectors. A key scientific rationale was that limited environmental variability in single-country studies likely underestimated the strength of associations between built environments and physical activity. Only pooled international data could provide accurate effect sizes based on the full range of global variation in built environments (46).

The IPEN Adult Study was conducted using common methods in 12 countries on 5 continents. Study coordination and data collection in some countries were funded by the United States National Institutes of Health/National Cancer Institute, but studies in most countries were supported by local funders. More than 14,000 adults aged 18–66 were recruited from neighborhoods in 17 cities that varied on built environment characteristics and neighborhood income. The study featured both objective and self-reported measures of physical activity and neighborhood environments, as well as weight and height measures (46).

Several IPEN Adult papers have reported the results of international pooled analyses of associations of built environment variables with multiple physical activity outcomes, sedentary behavior, body mass index (BMI), and overweight/obesity. However, it can be difficult for readers to integrate multiple topic-specific findings across individual papers in diverse journals. Thus, the overall goal of this review is to make the disparate findings more accessible by summarizing lessons learned from IPEN Adult and using common metrics to compute comparable effect sizes. The present article differs from other reviews in the *Annual Review of Public Health* in that it summarizes multiple results from one study rather than reviewing an entire literature. The article adds value to previously published findings by (*a*) reanalyzing and integrating results for five physical activity and obesity outcomes, (*b*) stratifying results by geographic information systems (GIS)–based and self-reported neighborhood environment measures, (*c*) reporting comparable magnitude of effects across outcomes, and (*d*) adding analyses for multifeature environment indexes when these were not included in the previous papers.

IPEN ADULT STUDY DESIGN AND OVERVIEW OF METHODS

The IPEN Adult Study was a coordinated multicountry cross-sectional study (46). Participating countries were selected to reflect variability in built and social environments, in combination with investigator capacity to implement the study design and collect physical activity and environment data. Participating cities and countries were Adelaide in Australia; Ghent in Belgium; Curitiba in Brazil; Bogotá in Colombia; Olomouc and Hradec Králové in the Czech Republic; Aarhus in Denmark; Hong Kong in China; Cuernavaca in Mexico; North Shore, Waitakere, Wellington, and Christchurch in New Zealand; Pamplona in Spain; Stoke-on-Trent in the United Kingdom; and Baltimore and Seattle regions in the United States.

Identifying Study Neighborhoods

For recruitment, neighborhoods were identified with a goal of maximizing variability in walkability and area-level socioeconomic status (SES). Neighborhood areas comprised clusters of small administrative units, such as census collection districts (Australia) or census block groups (United States), so the built environment could be assessed prior to participant recruitment. A minimum of 12 neighborhoods was required for each city.

The goal of the study design was to have equal numbers of neighborhoods across the following strata: high walkable/high SES, high walkable/low SES, low walkable/high SES, and low walkable/low SES. For the selection of study neighborhoods, most countries used a walkability index that was measured objectively using GIS at the smallest administrative unit where income was reported. For every administrative unit, a walkability index was derived as a sum of z-scores of at least two variables: (*a*) net residential density (ratio of residential units to the land area devoted to residential use); (*b*) land-use mix (diversity of land-use types; normalized scores ranged from 0 to 1, with 0 being single use and 1 indicating an even distribution of area across uses—e.g., residential, retail, entertainment, office, institutional); and (*c*) intersection density (connectivity of street network measured as the ratio of the number of intersections with three or more legs to land area). The walkability index is described elsewhere (36, 46).

Participant Recruitment

Participants aged 18–66 years were recruited from the neighborhoods identified. Potential participants were identified in most countries from commercial and government databases and recruited by mail, telephone, or personal visits. All participants completed written surveys, with subgroups of participants wearing accelerometers for seven days to objectively measure physical activity. Built environment variables around each individual's residential address were created in GIS. In most cities, participants were recruited over time equally from all neighborhood types to control for seasonal variability. Although the goal was for each country to use the same methods, in practice there were variations, as described previously (2, 17, 46). Study dates ranged from 2002 to 2011 across countries. Each country obtained ethical approval from local institutional review boards, and all participants provided written informed consent. Details on recruitment methods and response rates have been published (46).

Objective Environment Measures

GIS provide a framework and software for gathering, managing, and analyzing data related to spatial locations, which allow investigators to map and create quantitative variables. IPEN Adult used GIS methods to assess built environment variables known to be associated with physical activity (6, 27, 36). In a review of 50 built environment and physical activity studies, Brownson and colleagues (9) found large variability in how common built environment constructs were operationalized using GIS (i.e., variation in neighborhood scale, variable definitions, procedures to produce variables, types of metrics). Thus, it was a priority of IPEN investigators to develop measures of neighborhood environments around each participant's home that were as comparable as possible across participating countries (2).

First, investigators reached consensus about constructs to measure after considering existing evidence and feasibility of creating comparable variables. Second, acknowledging variations in access to data, we developed a hierarchy of required and desired variables. Third, we developed standardized templates for creating GIS variables that provided operational definitions and inclusion and exclusion criteria, offered concrete examples of GIS-based computations, and required countries to answer questions about procedures used, yielding detailed documentation of variable creation in each country. The templates are available in Adams et al. (1). Fourth, a comparability analysis was conducted by two experts who judged the degree of similarity in both definition and methods for each variable across countries. Fifth, country teams were asked to make changes to variables and/or methods for variables initially not judged to be comparable. GIS-based variables were calculated for 500-m and 1-km street-network buffers around participant homes. **Table 1** defines required built environment variables judged to be comparable and used across IPEN Adult papers. **Figure 1** shows that the IPEN Adult design achieved highly diverse built environments both within and between countries, documented by a ninefold difference in median walkability index values within 1 km around participant homes.

Table 1 GIS-based built environment measures used in the IPEN Adult Study

Measure	Definition
Neighborhood buffers (buffers are used in the computation of all the variables below)	An irregular-shaped polygon around a participant's geocoded home address. Buffer polygons were created for 0.5 km and 1.0 km network distances using ESRI's ArcGIS software (Redlands, California, USA). Buffers were created by tracing through the street network in all directions around each home to approximate accessible areas. The total area of the buffer was used as the denominator for density variables (except for net residential density). These buffer sizes were used to define features within walking distances of participants' homes.
Net residential density	Number of residential dwellings (houses and apartments) divided by the residential land area within neighborhood buffers (number of dwellings per km^2).
Land-use mix	1. Entropy score ranging from 0 to 1 based on a mix of residential, retail (including food and entertainment), and civic (public buildings) land areas. Values closer to 1.0 indicate an equal distribution of three land uses, and values closer to zero indicate that a single use dominates, typical in the case of predominately residential environments. 2. Ratio of retail and civic land area within a neighborhood buffer to total neighborhood buffer area.
Intersection density	Number of $\geq$3-arm intersections per km^2 in neighborhood buffer.
Transit density	1. Number of bus, rail, or ferry stops and stations divided by the land area within participants' buffers. 2. Network distance from participant homes to nearest transit stop or station.
Park access	A public park was defined as a government-designated park of any size that is free of cost, open to the public, and maintained by a government agency. Parks included improved or landscaped areas and unimproved or natural areas. 1. Number of public parks of any size in the neighborhood buffer, divided by the land area within participants' buffers. 2. Network distance from home to the nearest park. 3. Sum of total park area in neighborhood buffer.
Walkability index	Walkability index at participants' neighborhood buffer level is computed from pooled unstandardized data sets inclusive of all countries and cities = [(z-score for intersection density) + (z-score for net residential density) + (z-score for land-use mix)]

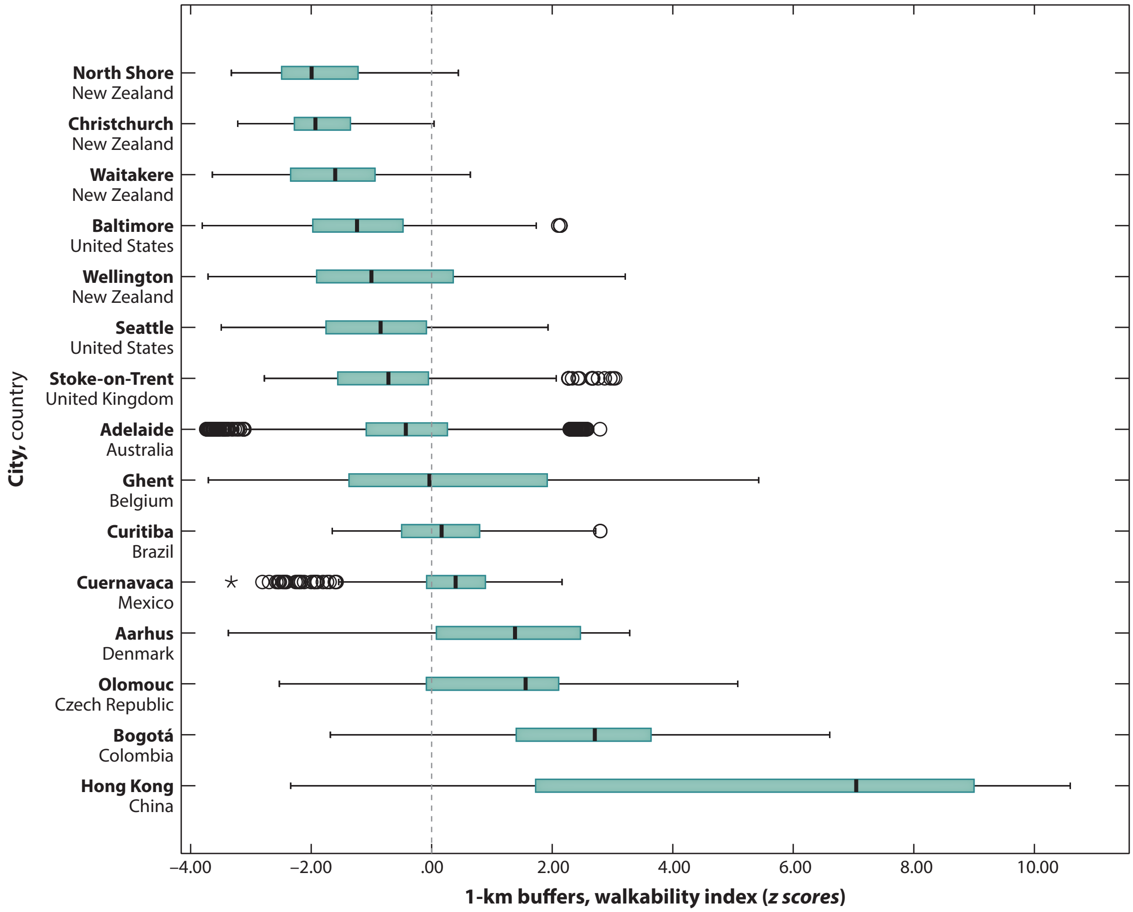

Figure 1

Walkability scores across cities and countries within participants' 1-km network buffer. Notes: For every administrative unit in a city, a walkability index was derived from at least two of the following variables: (*a*) street connectivity, (*b*) net residential density (ratio of residential units to the land area devoted to residential uses); and (*c*) land-use mix (diversity of land-use types), with normalized scores ranging from 0 to 1 and with 0 being single use and 1 indicating an even distribution of area across several types of uses (e.g., residential, retail, entertainment, institutional). Circles are outliers that extend past the whiskers, and asterisks represent extreme outliers defined as values greater than three times the length of the interquartile range. Adapted with permission from Adams et al. 2014 (2).

Self-Reported Environment Measures

Perceptions play an important role in the relationships between physical activity and built and natural environment features (7), and perceptions often differ from objectively measured environment characteristics (3). Self-report is the most appropriate method for assessing some important attributes, such as aesthetics and sense of safety. The Neighborhood Environment Walkability Scale (NEWS; 18, 19, 62) was used to assess neighborhood environment perceptions, with some variations across countries. Studies conducted in several countries reported high test–retest reliability (ICC > 0.75) for most scales (46). Confirmatory factor analysis was used to create subscales that maximized cross-country comparability and produced the following subscales: residential density, land-use mix—diversity, land-use mix—access, street connectivity, infrastructure and safety, aesthetics, safety from traffic, and safety from crime (17). Two items from the land-use

Table 2 Self-reported environment measures—Neighborhood Environment Walkability Scale (NEWS)[a]

Measure	Number of items	Explanation or items included
Residential density	4–6	Presence of various housing types (detached, townhouses, apartments with various heights)
Land-use mix: diversity (perceived proximity to local destinations)	Up to 13	Perceived walking proximity from home to various types of local destinations (e.g., supermarket, small grocery store, post office, any school, any restaurant, gym or fitness facility)
Land-use mix: access (not analyzed for present article)	2–3	Stores within easy walking distance; many places within walking distance[b]; easy to walk to transit stops
Street connectivity	2	Short distance between intersections; many alternative routes
Infrastructure and safety	3–6	Sidewalks, parked cars separating sidewalks and traffic[b]; grass/dirt separating sidewalks and traffic[b]; street lights; walkers and bikers easily seen[b]; crosswalks and pedestrian signals
Park proximity	1	Perceived walk time to nearest public park
Transit proximity	1	Perceived walk time to nearest transit stop or station
Aesthetics	3–4	Trees, many interesting things to look at[b]; many attractive natural sights; attractive buildings/homes
Safety from traffic	2–3	Heavy traffic along nearby streets; slow traffic speed on nearby streets; speeding drivers[b]
Safety from crime	3	High crime rate; unsafe to walk during the day; unsafe to walk at night

[a]Note: All measures were coded such that higher values were expected to be positively related to physical activity.
[b]Not included in some countries.

mix—diversity scale analyzed separately were proximity to a transit stop and proximity to the nearest park. Most items were rated from 1 (strongly disagree) to 4 (strongly agree), and scales were computed by averaging item scores. For residential density, participants' responses to the presence of various housing types were scored using a density-weighted formula (17). Land-use mix—diversity was assessed by asking participants to indicate how long it would take to walk to 13 destinations, with categories ranging from less than 5 minutes to more than 30 minutes (see **Table 2**).

Physical Activity Measures

All countries collected self-reported physical activity using the International Physical Activity Questionnaire—Long Form (IPAQ-LF), which collects data specific to activity domains (e.g., transport, leisure). There is substantial evidence of reliability and validity (24, 46). For present purposes, minutes per week of walking for transport and walking for leisure were analyzed. In the total sample, 73% of respondents had walked for transport (21) and 57% had walked for leisure within the last week (77).

Device-based measures of physical activity were collected using ActiGraph accelerometers (model 7164, 7125, GT1M, or GT3X; Pensacola, Florida), except for Australia, where no devices were used, and for New Zealand, where Actical monitors (Philips Respironics; Bend, Oregon) were used (14, 46). Participants were instructed to wear the monitors for seven days and all waking hours except during water activities. Four valid days were required to be included in analyses, 10 h of wear time was the minimum for a valid day, and the onset of nonwear time was 60 consecutive minutes of zero counts (10). Data were processed at the IPEN Coordinating Center using MeterPlus software version 4.3 and Freedson's cutpoint of 1,952 counts per minute for moderate to vigorous intensity physical activity (MVPA; 37). The average MVPA for the total sample was 38 minutes per day (14).

Despite their differences, both IPAQ-LF and accelerometer-measured physical activity data have been found to be reliable and valid (28). In the IPEN Adult Study, training, detailed guides, data-quality reviews, and analyses were implemented to ensure comparable measures across sites and accelerometer types (10, 14, 46).

Height and Weight

Body weight and height were measured in about half of the sites (Brazil, Hong Kong, Mexico, four New Zealand cities, United Kingdom) and self-reported in the other sites. BMI was calculated as weight (kg) divided by height (m) squared. BMI was classified into normal/lean weight (BMI $<$ 25) and overweight/obesity (BMI $\geq$ 25).

Data Analysis

The goal of analyses was to facilitate examination of selected results across eight papers from IPEN Adult, highlighting maximal differences in outcomes across worldwide variation in environments. To ensure comparability of variables, samples, and analysis procedures, new analyses were conducted for the present article. Associations of single environment variables and their composite index, which was the sum of z-scores of environment variables showing an association in the expected direction with the outcome, were calculated for each outcome variable. GIS-based and perceived environment variables were analyzed separately, and land-use mix—access was not analyzed because of overlap with land-use mix—diversity. Associations were estimated using generalized additive mixed models (GAMMs) with variance and link functions appropriate for the distributional properties of the outcome variables and accounting for clustering at the administrative-unit level arising from the two-stage sampling (90). Extending analyses of published papers, binomial variance and logit link functions were used to model overweight/obese status (0 = not overweight/obese; 1 = overweight/obese) (22, 26). Gamma variance and logarithmic link functions were used to model BMI (22, 26) and average daily minutes of accelerometry-assessed MVPA (14, 64). Reported minutes per week of walking for transportation (21, 45) and recreation (76, 77) were modeled using negative binomial and logarithmic link functions.

All models were adjusted for age, sex, education, marital status, employment status, area-level SES, and city (study site). These sociodemographic characteristics were chosen because they are established correlates of physical activity and/or weight status that were available across all study sites (6, 14, 26). Models were adjusted for area-level SES and city because they represented study design variables (i.e., variables used to select sites and administrative units within sites) that were not captured by the exposure variables of interest (e.g., built environment characteristics) (14). GAMMs of accelerometry-assessed MVPA were also adjusted for number of valid days of accelerometer wear and average daily minutes of wear time. Curvilinearity of relationships was assessed using thin-plate spline smooth terms (90). Smooth terms failing to provide sufficient evidence of curvilinearity, defined as a 10-unit difference in Akaike information criterion (AIC) between a GAMM with an exposure modeled using a thin-plate spline and a GAMM with the same exposure modeled using a linear term, were replaced by simpler linear terms. Analyses of data sets with more than 5% missing values on any of the examined variables were performed on ten imputed data sets created using chained equations (82).

Marginal means were estimated for three types of comparisons: the bottom 5% and 10%, top 5% and 10% of environment variables, and for the lowest and highest average city-level values of the environment variables. These comparisons were done to quantify effect sizes of single environment variables and composite environment indexes on outcomes (e.g., minutes per week of walking for transport). Then, absolute and relative (i.e., percent) differences (and 95% confidence intervals) between the pairs of the above-derived marginal values were computed. All analyses were conducted in R (58) using the packages "car" (30), "mgcv" (90), "gmodels" (86), and "mice" (83).

RESULTS

Tables 3 and **4** display the absolute and percent differences in marginal means (and their *p*-values) of outcome measures between the lowest 5% and highest 5% values for each environment variable. **Supplemental Tables 1–10** present more complete results for the lowest and highest 5% and 10% values of environment variables, as well as lowest and highest city-level environment values. Four of five GIS-based environment variables were significantly positively related to MVPA and walking for transport, three were related to walking for recreation, one to overweight/obesity, and none to BMI (**Table 3**). Mixed land use was the only GIS-based environment variable found to be unrelated to the examined outcomes. Overweight/obesity showed a stronger association with a GIS-based composite environment index than with single environment variables. The effect sizes of GIS-based environment variables were strongest for walking for transport, followed by MVPA and walking for recreation.

Supplemental Material >

Table 3 Magnitude of associations of GIS-based single environment variables and indexes with outcomes in the IPEN Adult Study[a]

	Outcomes				
Objective built environment—GIS based (based on 1-km network buffer)	**Total MVPA min/week (accelerometer) ($N = 6{,}822$)**	**Walking for transport min/week (reported) ($N = 11{,}674$)**	**Walking for leisure min/week (reported) ($N = 11{,}674$)**	**Body mass index ($N = 9{,}509$)**	**% Prevalence overweight/ obese ($N = 9{,}509$)**
Net residential density	29*** 12%	173[b]*** 169%	28*** 31%	−0.27– −1%	−2.1– −4%
Intersection density	31* 13%	179[b]*** 178%	30** 35%	−0.28– −1%	−5.3– −10%
Mixed land use (ratio of commercial + civic to residential)	8– 3%	5– 3%	3– 3%	0.05– 0%	0.1– 0%
Number of parks	21** 9%	35*** 25%	15* 17%	0.21– 1%	0.8– 2%
Number of transit stops	32*** 14%	23[c]* 20%	−2[c]– −2%	−0.22– −1%	−4.8* −9%
Multicomponent index (5 components)	35** 15%	81[c]*** 87%	25[c]** 29%	−0.16– −1%	−3.0– −6%
Index based on only 3 components with expected direction of association	NA	NA	NA	−0.38– −1%	−7.0* −13%

Abbreviations: GIS, geographic information systems; IPEN, International Physical Activity and the Environment Network; MVPA, moderate to vigorous intensity physical activity; NA, not applicable.

[a]Each cell contains absolute difference in the outcome between the bottom 5% and top 5% of the environment variable, proportional (%) difference, and symbol for *p*-value: –, nonsignificant; *, <0.05; **, <0.01; ***, <0.001.

[b]Curvilinear association.

[c]Adelaide excluded due to no data.

Table 4 Magnitude of associations of self-reported single-environment variables and indexes with outcomes in the IPEN Adult Study[a]

	Outcomes				
Reported built environment—NEWS	Total MVPA min/week (accelerometer) (N = 6,988)	Walking for transport min/week (reported) (N = 13,745)	Walking for leisure min/week (reported) (N = 13,745)	Body mass index (N = 14,222)	% Overweight/obese (N = 14,222)
Residential density	12– 5%	72*** 48%	34*** 37%	−0.22– −1%	−4.4* −9.0%
Land-use mix—diversity	33*** 14%	61*** 47%	24*** 27%	−0.54*** −2%	−4.2* −8.3%
Street connectivity	20** 8%	35*** 23%	13** 14%	−0.33** −1%	−1.9– −3.8%
Pedestrian infrastructure and safety	28*** 12%	36*** 22%	13* 14%	−0.40* −2%	−3.9* −7.8%
Park proximity	21** 9%	26** 18%	24*** 29%	−0.42*** −2%	−4.3* −8.4%
Transit proximity	1– 0%	9– 6%	0– 0%	−0.03– 0%	0.6– 1.3%
Aesthetics	20*** 12%	44*** 31%	52[b]*** 62%	−0.55** −2%	−3.2– −6.4%
Traffic safety	12– 5%	−20* −11%	4– 4%	−0.80*** −3%	−6.8*** −13.1%
Crime safety	16– 7%	−30** −16%	6– 6%	−0.84*** −3%	−4.1* −8.1%
Multicomponent index (7 components, excluding traffic safety and crime safety)	41*** 18%	77*** 60%	39*** 48%	−0.76*** −3%	−5.5** −10.8%
Index based on only 6 components with expected direction of association	NA	NA	NA	NA	−6.9*** −13.3%

Abbreviations: IPEN, International Physical Activity and the Environment Network; MVPA, moderate to vigorous intensity physical activity; NA, not applicable; NEWS, Neighborhood Environment Walkability Scale.

[a]Each cell contains absolute difference in the outcome between the bottom 5% and top 5% of the environment variable, proportional (%) difference, and symbol for p-value: –, nonsignificant; *, <0.05; **, <0.01; ***, <0.001.

[b]Curvilinear association.

Five to seven out of nine perceived environment variables were significantly associated in the expected direction with each of the outcomes (**Table 4**). Perceived transit stop proximity was the only attribute found to be unrelated to the outcomes, possibly owing to its limited variability. Land-use mix—diversity, pedestrian infrastructure and safety, and park proximity were consistently associated in the expected direction with all outcomes. Intersection density and aesthetics were associated with all the outcomes in the expected direction, except for overweight/obesity. Perceived safety measures showed associations in the expected direction with walking for transport, BMI, and overweight/obesity only. Similarly to their GIS-based counterparts, perceived environment variables were most strongly related to walking for transport. Perceived composite indexes showed stronger relations than single environment variables with MVPA, walking for transport, and overweight/obesity (**Table 4**).

DISCUSSION

Capitalizing on the wide international variability in built environments, this article integrates, extends, and further interprets the results from eight IPEN Adult publications. By comparing physical activity and weight status of residents of the least and most activity-supportive environments for each built environment variable, as well as multivariable indexes, the present findings go beyond what has been reported in individual IPEN Adult papers, highlighting the international significance of built environment improvements as a promising public health intervention strategy.

Effect Sizes

Effect sizes of associations between environment variables and physical activity outcomes were substantial. The differences in MVPA minutes per week across the 5% least and most activity-supportive neighborhoods were 35 minutes per week for environments measured by GIS and a similar 41 minutes per week by self-report measures. For both types of measures, the multicomponent environment indexes had the strongest associations with MVPA. The difference in MVPA between the lowest 5% and highest 5% activity-supportive neighborhoods was surprisingly similar to the difference between lower- and higher-walkability neighborhoods as previously reported for US (35–47 minutes per week; 69) and Belgian (48 minutes per week; 85) cities. Although investigators expected that MVPA effect sizes would be greater when comparing across more diverse international environments, that result was not found to be true when comparing the 5% least and most activity-supportive neighborhoods in IPEN Adult.

When comparing MVPA across the most and least activity-supportive cities on average in a previous publication (64), we found that the difference was a much larger 69–89 minutes per week (see **Supplemental Table 1** for detailed results for all three comparisons). The largest MVPA difference was seen for residential density in the comparison of cities. Because Hong Kong had much higher density than did the other cities, the range of densities was very large when cities were compared. However, the high densities were diluted when the 5% lowest- and highest-density neighborhoods were compared (as reported in **Table 3**) because the Hong Kong subsample was small (269 participants with valid MVPA data) and corresponded to less than 5% of the total sample. Though results across the three types of comparisons vary (see **Supplemental Tables 1–10**), all comparison methods confirm substantial potential beneficial effects when comparing across neighborhoods defined by multiple activity-supportive features.

Supplemental Material >

For the walking for transport outcome, the maximum effect size was 179 minutes per week for GIS-based environment measures, and the strongest GIS-based associations were with intersection density and residential density. The maximum effect size for self-reported environment variables was 77 minutes per week for the index. For the walking for leisure outcome, the maximum effect sizes were 30 minutes per week for GIS (intersection density) and 52 minutes per week for self-reported environment measures (aesthetics). Though self-reported absolute minutes of walking should be interpreted cautiously, the environment-comparison percentage differences of 60–178% for walking for transport and 35–62% for walking for leisure suggest strong potential impacts of improving activity-supportive neighborhood environments.

Environment Correlates Across Physical Activity Domains

Environment correlates were hypothesized to be specific to the domain of physical activity (65, 68), but this hypothesis was not strongly supported. Walkability-related variables (e.g., residential density, intersection density, mixed land use) were most strongly related to walking for transport, as expected, but most of these variables were also related to walking for leisure. Thus, in this international study, neighborhoods designed to support transport walking also appeared to facilitate walking for leisure, as well as total MVPA. The strongest correlate of walking for leisure was self-reported aesthetics, which is a domain-specific association consistent with many prior studies (52, 61), but aesthetics was also significantly related to walking for transport and total MVPA. Reported pedestrian infrastructure and GIS-based park density were related to all three physical activity measures, providing evidence that sidewalks and parks should be considered important health resources. Because walking is the most common activity for leisure and transport, sidewalks appear to support walking in general. Parks can be a place for leisure activity and a destination, so these are examples of the multiple functions of activity-supportive built environments. An important finding from IPEN Adult was that, when the entire global range of environments was examined, almost all built environment measures were related to all three physical activity measures, indicating broad benefits of activity-supportive design for physical activity rather than domain-specific benefits.

Built Environments and Weight Status

Although most self-reported environment variables were significantly related to BMI, the effects were small, with a maximum 3% difference between the least and most activity-supportive neighborhoods. However, the relative effect sizes for environment variables were much stronger for the prevalence of overweight/obesity, ranging up to 13.3% for one index. More than half of the self-report environment variables had effect sizes greater than 8% for overweight/obesity. Effect sizes may have been weaker for BMI because physical activity would be expected to mediate weight control at higher levels of BMI and would not be expected to further reduce low BMIs. The single variables with the strongest associations with overweight/obesity were both transport related: GIS-based density of transit stops and reported traffic safety. These findings suggest car-focused transportation policy and investments may be an underrecognized contributor to obesity internationally (50, 51). Time in cars is a risk factor for obesity (31, 50, 51, 78). An unexpected finding was that perceived traffic safety and crime safety appeared to be protective from overweight/obesity, but neither was positively related to physical activity. The association of the safety variables to overweight/obesity has rarely been evaluated (56, 91), but the lack of associations with physical activity emphasizes the complexity and inconsistency of safety-related findings that have been highlighted in a review by Foster & Giles-Corti (29).

Comparing GIS-Based and Self-Report Environment Variables

Present results allowed investigators to compare the performance of objectively measured and self-reported environment variables in explaining outcomes. Both types of built environment variables were consistently related to physical activity, particularly residential density and intersection density. GIS-measured park density and reported park proximity were significantly associated with all three physical activity measures. Self-reported mixed land use was related to all physical activity variables, but the GIS measure was related to none. This pattern is interpreted as supporting the importance of mixed use as a construct but confirming the limitations of international data used in this GIS measure, as described in a prior publication (64). Public transit access was related to two of three physical activity outcomes when measured with GIS but related to no outcomes when self-reported. Self-reported proximity to a transit stop had very low variability; the vast majority of participants reported nearby transit stops, indicating limitations of the one-item measure. IPEN Adult results strongly support the utility of both GIS-based and self-reported environment variables, although limitations of specific variables were revealed.

The performance of GIS-based and self-reported environment measures in explaining weight status outcomes was more complex. The most obvious finding was that almost all self-reported environment variables were significantly related to weight status, compared with very few significant associations for GIS-measured environment variables. The only common finding was that multicomponent index variables were significant for the relation of both GIS-based and self-reported environment variables with overweight/obesity, reinforcing the importance of multivariable conceptualization and measurement of environments. The limited findings with GIS-based variables were partly explained by the sex-specific associations with weight status reported in the original paper (22).

Consistent Support for Multivariable Built Environment Indexes

Multivariable environment indexes were significant for all outcomes, regardless of whether environments were measured objectively or by self-report. In half of the cases, the index had the strongest association with the outcome. The only exception was that the GIS-based multicomponent indexes were not significantly related to BMI. Studies that examine only single variables and do not evaluate indexes may underestimate associations of built environments with health outcomes. The consistent support in this international study for the importance of the combination of built environment variables to support physical activity and healthy weights extends prior findings about indexes that have been less consistent in single-country studies (6, 27).

In a notable finding, both absolute and relative differences in outcomes were very similar for environment indexes created from GIS-based and self-reported environment variables. Although discrepancies and biases in self-reported environment measures have been documented (3, 16), the strength and significance of associations were similar for GIS-based and self-reported measures. These findings support the utility and continued use of both modes of environment measures. Using self-report environment measures is likely to be the only option for future studies of low-income countries where GIS data are often not available. The greater number of variables in the self-report indexes may have enhanced their explanatory power, and the ability of self-reports to assess constructs not available in GIS databases is an advantage of self-reports.

The strong performance of environment indexes supports implementation of multiple strategies to improve built environments. Evaluations of built environment interventions involving multiple and substantial changes generally support the efficacy of these interventions for increasing physical activity (20, 23, 43, 57).

Generalization Across Cities and Shape of Associations

The reanalyses presented here have focused on effect sizes, but results in the published papers also addressed generalization across cities and the shape of associations, assessing for curvilinearity. Clear evidence demonstrated that results generalized very well across highly diverse cities. Across the 208 relevant models reported in the main outcome papers, only 17 (8%) had significant environment-by-city interactions. These surprisingly uniform results suggest that associations of built environments with multiple physical activity and weight status outcomes are internationally generalizable principles. Although there may be exceptions in countries that were not part of IPEN Adult, with particular concern about low-income countries that were not represented, the evidence of generalizability provides confidence about the utility of IPEN findings as one input into policy discussions.

Across the 208 relevant models in the original papers, only 11 (5%) had significant curvilinearity. The figures indicated a variety of patterns, with no one dominant pattern. Only two comparisons in present reanalyses had evidence of curvilinearity. Thus, associations of built environment attributes with physical activity and weight status are largely linear across the wide international variability, suggesting that enhancing activity supportiveness of neighborhoods could be expected to increase physical activity, regardless of the initial level.

Limitations

The most important limitation of the IPEN Adult Study is its cross-sectional design, which does not allow interpretations of causality. Cross-sectional designs are frequently criticized in the built environment and physical activity literature (27). However, a recent review found that prospective data and evaluations of natural experiments were generally consistent with cross-sectional results, leading to a recommendation from the US Guide to Community Preventive Services that combinations of built environment and transport environment changes were evidence-based strategies for increasing physical activity (23).

A related weakness was an inability to adjust analyses for self-selection bias because several countries did not measure this variable. However, residential mobility is uncommon in many countries, so this bias may not be as important in international studies. Studies in affluent countries demonstrate that adjustment for self-selection usually attenuates, but does not eliminate, associations of environments with physical activity (12, 84).

Lack of low-income countries in the IPEN Adult Study was a limitation, mainly owing to the limited capacity of investigators from low-income countries at the initiation of the study. Following the capacity building of IPEN Adult, we were able to include several low-income countries in the IPEN Adolescent Study (**http://ipenproject.org/IPEN_adolescent.html**). Rural areas were excluded from the present study because we lack definitions of activity-supportive built environments for rural areas (42). Growing evidence indicates that people living in walkable communities may be exposed to higher levels of local air pollution, though they drive less (34). Potential negative side effects of built environments, such as air pollution, were not assessed. Some measures were shown to be problematic, such as GIS-based mixed use and self-reported public transit access. Finally, detailed observational measures of streetscapes, park quality, and water features were not collected, and their inclusion could have strengthened associations of neighborhood environments with outcomes.

Implications for Policy and Practice

One of the objectives of IPEN Adult was to conduct a policy-relevant study and then communicate findings to policy and practice audiences (38). IPEN Adult results provide policy makers with an evidence-based rationale to pursue transportation and land-use actions that are outside current agency practices, which in many countries strongly prioritize automobile travel and separation of land uses. It can be difficult, without compelling evidence, for city leaders to credibly argue that their cities should "grow up and not out" and adopt different development goals and policies. IPEN evidence can be used to raise awareness that changing agency practices and goals can result in considerable payoffs, at least for physical activity and obesity. IPEN Adult results show that the human-behavior relationship with the built environment is relatively stable across diverse countries. Therefore, IPEN Adult findings both substantiate and strengthen arguments for designing communities to enhance health (32), informing global approaches to policies and practices within urban planning, transport, and parks sectors. City leaders do not need to rely only on IPEN Adult data because growing prospective and natural experiment evidence led the US Guide to Community Preventive Services to recommend combinations of land use and transportation interventions (23), and the World Health Organization (WHO)'s Global Action Plan on Physical Activity features "create active places" as one of its four main strategies (89).

While IPEN findings may be useful to bolster political will to change how new communities are being built and existing communities are retrofitted, resistance to change is common and powerful. For example, resistance to densification has long been a focus of NIMBY-ism (i.e., not in my back yard) and has slowed or blocked the creation of compact walkable communities around transit nodes for decades (49). A common argument in local debates is that evidence from elsewhere is not generalizable here and "we" are not like "them." Results presented here suggest "we" probably are like "them," and data collected elsewhere applies across seemingly different cities and countries. IPEN Adult evidence may help reframe debates to emphasize the health benefits of density as part of health-promoting community design. Present results offer progressive leaders credible evidence and may enhance their political will to pursue more ambitious transit and active transportation investments and walkability-focused land-use policies.

Additional Contributions of IPEN

Advancing measurement through IPEN. The IPEN Adult Study and broader group of IPEN investigators generated several measurement resources, improved understanding of performance of measures in an international context, and developed new measures. Resources that can support further international studies include the GIS protocol manual (1, 2) and accelerometer protocol and training materials (10). New measures included adaptations of the NEWS neighborhood environment survey tailored for sub-Saharan Africa (53, 54) and India (4, 5) and development of an internationally applicable instrument for observing streetscape characteristics (11). Methodological studies examined the validity of different ways of defining buffers in GIS around homes (33), found curvilinear associations between GIS-measured and self-reported environment variables (16), and reported variation across countries in agreement between self-reported and accelerometer-based measures of physical activity (15).

Latin American IPEN collaboration. IPEN Adult contributed to strengthening regional research capacity and context-specific results for Latin America. Before IPEN Adult, little evidence was available to guide built environment research and practice in this region, which is the world's most urbanized region (80% of Latin Americans live in cities) (72, 81). By participating in this international study, IPEN-Latin America (IPEN-LA) investigators not only gained new research skills via direct trainings (e.g., accelerometer processing, GIS, spatial analysis), but also created a productive regional collaboration. The IPEN-LA teams from Brazil [principal investigator (PI): Rodrigo Reis], Colombia (PI: Olga Lucia Sarmiento), and Mexico (co-PIs: Deborah Salvo and Michael Pratt) worked cohesively to adapt IPEN methods for the Latin American context, including new supplemental survey measures.

Findings from the collaboration included identification of features of the built environment, in addition to walkability, that help explain geospatial variability of physical activity in Latin America (40, 44, 59, 73). IPEN-LA findings showed that streets were the most common place for active transport, leisure-time walking, and device-assessed MVPA (74). In Latin America, nontraditional settings designed for social interaction, such as public plazas, informal soccer courts, and shopping malls, mattered as much for physical activity as did traditional settings designed for exercise and sport (74).

The IPEN-LA team explored the role of car ownership on physical activity to propose a necessity-driven versus choice-driven framework for understanding physical activity in Latin America (72, 74, 75). The necessity-driven framework seems most appropriate when applied to cities with high prevalence of transport-based physical activity, coupled with low prevalence of leisure-time physical activity and low proportion of car ownership. This framework has been adopted in studies of other low- and middle-income countries (5, 71).

IPEN Adolescent Study. Experience with the IPEN Adult Study was applied to planning and conducting an IPEN Adolescent Study (**http://ipenproject.org/IPEN_adolescent.html**), with analyses in progress.

SUMMARY POINTS

1. Neighborhood environment attributes were strongly related to all physical activity outcomes and meaningfully related to overweight/obesity. Activity-supportive built environments should be a higher international health priority.
2. Measuring environments by GIS or self-report yielded similar associations with all physical activity and weight status outcomes. This pattern of findings justifies continued use of both measurement modes.
3. Although numerous previously studied single-environment attributes were favorably related to multiple outcomes, multivariable environment indexes were significantly related to all outcomes, adding evidence in support of recommendations for combinations of environment interventions (23). The implication is that each type of environment improvement is likely to provide additional benefits for physical activity and weight status outcomes.
4. Contrary to expectations of domain-specific associations of physical activity with environment attributes, built environment variables were related to all physical activity measures, indicating broad benefits of activity-supportive design.
5. Environment variables are affected by policies in multiple government agencies: transportation, city planning, and parks and recreation (39). Thus, present results provide evidence to guide policy actions by governments worldwide, at least in middle- and high-income countries similar to those participating in IPEN Adult.
6. Physical activity and obesity control are important rationales for designing cities to be activity supportive, but reviews show additional benefits of active design regarding physical and mental health, environmental sustainability (air pollution and carbon emissions), and economic performance (70).
7. Present results highlighting the maximal potential impact of built environments across the world demonstrated substantial effect sizes. Although it may be unrealistic for the least activity-supportive cities to be transformed to be among the most activity supportive, the evidence of linear associations and generalizability across diverse countries provides reassurance that meaningful built environment improvements should translate to meaningful physical activity and weight status improvements.
8. Present results provide evidence in support of major global initiatives, such as the United Nations Sustainable Development Goals (**https://sustainabledevelopment.un.org/?menu=1300**), WHO's Global Action Plan for NCDs (88), WHO's Global Action Plan for Physical Activity (89), and numerous national physical activity plans (8).

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AUTHOR CONTRIBUTIONS

J.F.S. conceptualized this review, drafted much of the Introduction and Discussion sections, created the **Supplemental Acknowledgments**, and served as the primary editor. E.C. planned and conducted all analyses, drafted the Data Analysis and Results sections, and created the **Supplemental Tables**. J.K. drafted the IPEN Adult Study Design and Overview of Methods introduction, Selection of Neighborhoods section, and Participant Recruitment section. M.A.A. drafted the GIS methods in the IPEN Adult Study Design and Overview of Methods section. T.S. drafted the perceived environment methods in the IPEN Adult Study Design and Overview of Methods section. L.B.C. drafted the physical activity methods in the IPEN Adult Study Design and Overview of Methods section. J.S. drafted parts of the Introduction and Discussion. R.D. drafted the weight and height methods and contributed to other subsections in the IPEN Adult Study Design and Overview of Methods section. D.S. drafted the Latin American IPEN Collaboration section. L.D.F. drafted the Implications for Policy and Practice section. I.D.B. drafted multiple parts of the Discussion section. N.O. contributed to the article's conceptualization, drafted parts of the Discussion, and served as the secondary editor. All authors edited the manuscript and approved the final version.

Supplemental Material >

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