Published in final edited form as:
Med Sci Sports Exerc. 2014 December ; 46(12): 2253–2264. doi:10.1249/MSS.0000000000000367.

Neighborhood Environments and Objectively Measured Physical Activity in 11 Countries

Ester Cerin[1,2], **Kelli L Cain**[3], **Terry L Conway**[3], **Delfien Van Dyck**[4], **Erica Hinckson**[5], **Jasper Schipperijn**[6], **Ilse De Bourdeaudhuij**[4], **Neville Owen**[7], **Rachel C Davey**[8], **Adriano Akira Ferreira Hino**[9], **Josef Mitáš**[10], **Rosario Orzanco-Garralda**[11], **Deborah Salvo**[12,13,14], **Olga L Sarmiento**[15], **Lars B Christiansen**[6], **Duncan J Macfarlane**[2], **Grant Schofield**[5], and **James F Sallis**[3]

[1]Centre of Physical Activity and Nutrition Research, School of Exercise and Nutrition Sciences, Deakin University, Burwood, Victoria, Australia [2]Institute of Human Performance, The University of Hong Kong, Hong Kong, China [3]Department of Family and Preventive Medicine, University of California, San Diego, USA [4]Department of Movement and Sport Sciences, Ghent University, Ghent, Belgium [5]Auckland University of Technology, Human Potential Centre, Auckland, New Zealand [6]Department of Sports Science and Clinical Biomechanics, University of Southern Denmark [7]Baker IDI Heart and Diabetes Institute, Melbourne, Australia [8]Centre for Research & Action in Public Health, Canberra University, Canberra, ACT, Australia [9]Department of Physical Education, Federal University of Parana, Curitiba, Brazil [10]Institute of Active Lifestyle, Faculty of Physical Culture, Palacký University, Olomouc, Czech Republic [11]Department of Health Sciences, Public University of Navarra, Pamplona, Navarra, Spain [12]Center for Nutrition and Health Research, National Institute of Public Health, Cuernavaca, Morelos, Mexico [13]Stanford Prevention Research Center, Stanford University School of Medicine, Palo Alto, CA, USA [14]Nutrition and Health Sciences Program, Graduate Division of Biological and Biomedical Sciences, Emory University, Atlanta, USA [15]Universidad de los Andes, Department of Public Health, School of Medicine, Bogotá, Colombia

Abstract

Purpose—Environmental changes are potentially effective population-level physical activity (PA) promotion strategies. However, robust multi-site evidence to guide international action for developing activity-supportive environments is lacking. We estimated pooled associations of perceived environmental attributes with objectively-measured PA outcomes; between-site differences in such associations; and, the extent to which perceived environmental attributes explain between-site differences in PA.

Methods—This was a cross-sectional study conducted in 16 cities located in Belgium, Brazil, Colombia, Czech Republic, Denmark, China, Mexico, New Zealand, Spain, United Kingdom, and USA. Participants were 6,968 adults residing in administrative units stratified by socio-economic status and transport-related walkability. Predictors were 10 perceived neighborhood environmental

Correspondence to: Ester Cerin, C-PAN, School of Exercise and Nutrition Sciences, Deakin University, 221 Burwood Highway, VIC 3125, Australia, Tel: +61 3 92446773, Fax: +61 3 92446017, ecerin@hku.hk.

attributes. Outcome measures were accelerometry-assessed weekly minutes of moderate-to-vigorous PA (MVPA) and meeting the PA guidelines for cancer/weight gain prevention (420 min/week of MVPA).

Results—Most perceived neighborhood attributes were positively associated with the PA outcomes in the pooled, site-adjusted, single-predictor models. Associations were generalizable across geographical locations. Aesthetics and land use mix – access were significant predictors of both PA outcomes in the fully-adjusted models. Environmental attributes accounted for within-site variability in MVPA corresponding to a 3 min/d or 21 min/week standard deviation. Large between-site differences in PA outcomes were observed: 15.9% to 16.8% of these differences were explained by perceived environmental attributes. All neighborhood attributes were associated with between-site differences in the total effects of the perceived environment on PA outcomes.

Conclusions—Residents' perceptions of neighborhood attributes that facilitate walking were positively associated with objectively-measured MVPA and meeting the guidelines for cancer/weight gain prevention at the within- and between-site levels. Associations were similar across study sites, lending support for international recommendations for designing PA-friendly built environments.

Keywords

Adults; Built environment; Cancer prevention; Multi-site study

INTRODUCTION

Physical inactivity is associated with an increased risk of all-cause mortality and several globally-prevalent non-communicable diseases, including cardiovascular diseases and some types of cancer (28,36,39). While for general health it is recommended that adults accumulate at least 150 weekly minutes of moderate intensity physical activity (PA) (39), the recommended dose of PA for cancer prevention is 420 minutes a week (60 min/d) (36), which is also the suggested amount for weight gain prevention (27). These are ambitious PA targets that only a minority of the global population meets (1,2,8) and that require international and national strategies to promote PA with sustained population-wide effects (26).

Environmental changes have been identified as potentially effective population-level PA promotion strategies because they can potentially affect the behavior of a large number of people for a sustained amount of time (22). Studies examining the potential effect of the built environment on PA have used objective and/or perceived (self-report) measures to assess characteristics of the neighborhood environment (3,18,30). These methods offer somewhat different but equally important information contributing to a better understanding of PA behavior (30). While the correspondence between objective and perceived measures of the environment is far from being perfect (18), there is evidence that perceptions of the environment are in part a reflection of the actual environment (9,18) and, thus, can provide useful, although not always accurate, information on the actual neighborhood environment. Objective and perceived neighborhood features such as the actual or perceived presence of footpaths and easy access to a diversity of destinations (land use mix) have been associated with higher levels of PA (3), particularly walking (13,30,34). Nevertheless, good quality evidence to guide international action aimed at developing activity-supportive environments is lacking. This is because most studies of built environments and PA have been conducted in Western countries (3), with restricted variability in environmental exposures and PA (25). Research on environmental correlates of PA has only recently been extended to locations other than Canada, the USA, Australia and Europe (3,11,23). However, most studies have not employed common methods, making comparison and synthesis of findings difficult.

The 11-country International Prevalence Study that included common methods and a wide range of environments found stronger pooled estimates of associations with PA compared to single-country studies (32). However, it also unveiled substantial between-country differences in perceived environment-PA associations, highlighting the need to base decisions about specific environmental change targets on local data (13). Despite its strengths, the previous 11-country study (i.e., the International Prevalence Study) used single-item self-report environmental measures that were not cross-validated across the participating sites; self-report measures of PA which are likely to be affected by socio-cultural factors (29); and, a design that did not maximize the environmental variability within and across countries. Thus, the shape, magnitude, and generalizability of relationships of objective and perceived neighborhood environment characteristics with PA remain unclear. This is especially the case for the more ambitious PA recommendations for cancer and weight gain prevention, as the environmental correlates of these have never been investigated. This is at odds with the fact that, among non-communicable diseases, cancer is the second leading cause of premature death (36). Also, overweight/obesity is the fifth leading risk contributing to premature deaths worldwide (37). Therefore, there is a genuine need for identifying environmental factors related to meeting the PA guidelines for cancer and weight gain prevention globally.

The extent to which perceived attributes of the built environment explain between-site differences in PA is also unclear. Although there is great variability in population PA levels across geographical locations (2,19,20), studies have examined site-adjusted associations of perceived environment with PA (13,32) but never quantified the potential contribution of perceived environmental factors to the observed between-site differences in PA. A measure of site-adjusted environment-PA associations represents the average association observed across sites. As such, it cannot reveal why sites differ in levels of PA. As a matter of fact, the environmental factors contributing to between-site differences in PA may substantially differ from those contributing to within-site differences (24). Thus, important, population-level environmental contributors to PA can go unnoticed in studies focusing on within-site associations.

Using comparable measures and a common protocol, the aims of this new multi-site cross-sectional study, named the International Physical Activity and the Environment Network (IPEN) Adult study (25), were to estimate (a) pooled associations of perceived environmental attributes hypothesized to facilitate PA (10,31) with objectively-assessed daily minutes of moderate-to-vigorous PA and meeting the PA guidelines for cancer/weight gain prevention; (b) between-site differences in such associations; and, (c) the extent to which perceived environmental attributes explain between-site PA differences.

Data were collected from 16 cities located in 11 countries across five continents, using a common protocol (25). We hypothesized that associations would be generalizable across sites to a greater extent than previously observed (13) due to the use of objective measures of PA, which should be unaffected by socio-cultural response biases. Since unmeasured socio-cultural factors (29) and climatic conditions can substantially influence engagement in PA (4), we also hypothesized that perceived environmental factors would explain only a moderate portion of the between-site difference in PA estimates.

Methods

Neighborhood selection

The IPEN Adult study is an observational epidemiologic multi-country cross-sectional study that includes 17 city-regions (hereafter, 'sites') located within 12 countries (note that Australia is not included in current analyses; see *Recruitment and Participants* section below): 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), United Kingdom (Stoke-on-Trent), and United States of America (Seattle, Baltimore). In all participating countries, prior to recruiting any study participants, neighborhoods within each site were selected to maximize the variance in neighborhood walkability and socio-economic status (SES).

The goal of the IPEN study design was for each site to select participants from an equal number of neighborhoods stratified to fall within one of four quadrants defined as: high walkable/high SES, high walkable/low SES, low walkable/high SES, and low walkable/low SES. For neighborhood selection, all countries (except Spain, which used alternate proxy measures) used an objectively defined walkability index using Geographic Information Systems data and census-level SES indicators (25). The walkability index was computed for all areas across the site's entire region using the smallest administrative unit available. Detailed neighborhood selection procedures have been documented elsewhere (15,25).

Recruitment and participants

The recruitment strategy for IPEN Adult required systematic selection of participants residing in the selected neighborhoods. Participants were contacted and invited to complete a survey on their PA and perceptions of the environment, and wear accelerometers to measure objective PA. Some countries asked only a subset of participants to wear accelerometers (see Table 1). Each country obtained ethical approval for using human subjects from their local institutional review boards, and all participants provided informed consent prior to data collection. Study dates ranged from 2002 to 2011. Age ranges at recruitment spanned from 15–84 years (N=14, 309). We only included participants in the 18–66 years age range as only three sites had a wider age range than this. The resulting sample size was 14,222. Six sites recruited participants by phone and mail, and 10 study sites contacted households in person. Seven study sites employed self-administered methods (mail and online surveys) to collect survey data, eight sites used interviews, and two sites employed both self-administered and interview methods. Further details about participant recruitment, response rates and sample sizes have been published elsewhere (25).

One study site (Adelaide, Australia) did not collect objective PA data (n=2650). A proportion of the remaining 11,572 participants from 16 sites did not wear an accelerometer, either because they did not consent to wearing it or the site could not afford collecting accelerometer data on all participants. For the sites aiming to collect accelerometer data on all recruited participants, the proportions of participants that consented to wearing the accelerometers ranged from 86.5% to 100%. In general, when compared to participants who did not wear accelerometers (n=3304) or had less than four valid days of accelerometer data (n=502), those who had at least four valid days of wearing time (n=7, 273) were more likely to be older (p<.001), married (p=.012), employed (p=.005), hold a tertiary degree (p=.001) and live in neighborhoods perceived to have higher levels of safety from crime (p=.025) and pedestrian infrastructure/safety (p=.043). The socio-demographic characteristics of the sample with valid accelerometer data by study site are presented in Table 1.

Measures

Neighborhood Environment Walkability Scale (NEWS)—The NEWS assesses perceived neighborhood attributes related to walking. A requirement for inclusion in the IPEN Adult study was that each country had to include either the full version of the NEWS (31) or the abbreviated NEWS-A (10). 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, an extensive undertaking of item comparisons and confirmatory factor analyses were completed to compare the NEWS/NEWS-A items used in each country and confirm scales could be constructed that were comparable across the 12 IPEN countries (7). The resulting 10 NEWS measures constructed for the IPEN Adult study gauge the following perceived neighborhood attributes: Residential density; Land use mix – diversity; Land use mix – access; Street connectivity; Infrastructure and safety for walking; Aesthetics; Traffic safety; Safety from crime; Streets having few cul-de-sacs; and No physical barriers to walking.

The *Residential density* subscale is a weighted sum of items reflecting perceived density of housing. The *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 elsewhere (7).

Accelerometer-measured physical activity—PA was measured objectively with accelerometers, which are a widely used method to objectively characterize intensity and duration of free living PA, with their reliability and validity extensively documented (17). Four sites mailed accelerometers to participants, 13 sites delivered and retrieved them in person, and one site used both delivery methods. Participants were asked to wear the accelerometer around their waist on a belt with the device oriented above the right hip for 7 days during waking hours when not engaged in water activities (e.g., showering). Twelve sites used an ActiGraph device (Pensacola, FL) and the New Zealand sites used the Actical (Philips Respironics, Bend, OR). See the accelerometer protocol for further details (6).

Accelerometer data were either collected with or aggregated to 1-minute epochs. Non-wear time was defined as 60 or more minutes of consecutive '0' activity counts. Data were screened and processed using MeterPlus version 4.3 (www.meterplussoftware.com) by trained researchers at the IPEN Coordinating Center. All days identified as 'wearing' days were scored but only days consisting of at least 10 wearing hours were coded as valid. Participants were included in analyses if they had at least 4 valid wearing days (including a weekend day).

For Actigraph data, vertical plane activity counts were converted to minute estimates of moderate and vigorous PA using the Freedson cut points (16). For the omni-directional Actical data (New Zealand sites), new moderate and vigorous intensity cut points were developed to enable comparison between the ActiGraph-Freedson and Actical estimates. Optimal Actical cut points for predicting Actigraph moderate and vigorous PA (using the Actigraph-Freedson estimates as the criterion) were determined to be 730–3399 cpm for moderate and ≥3400 cpm for vigorous intensity (6). The agreement between Actical and Actigraph-Freedson estimates of time spent in specific activity intensities was 97.2% (Kappa= 0.658 ± 0.013; p<.001) for moderate, 98.8% (Kappa= 0.203 ± 0.030; p<.001) for vigorous and 98.4% (Kappa= 0.837 ± 0.009; p<.001) for MVPA (6).

Daily minutes in each PA intensity were summed across valid wearing days and divided by the number of valid days to compute the average daily minutes of moderate-to-vigorous physical activity (MVPA). Additionally, using the average daily minute measures multiplied by 7 days, a variable was created to indicate whether participants met the PA guidelines for cancer and weight gain prevention of at least 420 min/week of moderate intensity or 210 min/week of vigorous intensity activity (27,36).

Socio-demographic covariates—Although countries assessed different socio-demographic variables in their studies, five were common across all countries and were adjusted for in the models to determine pooled associations. These were self-reported and included: age (in years), sex, marital status (recoded as married or living with a partner versus not), educational attainment (recoded as less than high school graduate; high school graduate and/or some college; college degree or higher), and employment status (having vs. not having a job).

Data Analytic Plan

Descriptive statistics were computed for the whole sample with at least four valid days of accelerometer data and by study site. Associations of perceived environmental variables with PA outcomes were estimated using generalized additive mixed models (GAMMs) (40).

GAMMs can model data following various distributional assumptions (e.g., positively skewed), account for dependency in error terms due to clustering (participants recruited from selected administrative units), and estimate complex, dose-response relationships of unknown form. Preliminary analyses indicated that GAMMS with Gamma variance and logarithmic link functions would be most appropriate for the continuous measure of MVPA. The reported antilogarithms of the regression coefficient estimates of these GAMMs represent the proportional increase in daily minutes of MVPA associated with a unit increase in the correlates. For example, a value of 1.17 would be interpreted as a 17% increase in min/day of MVPA associated with a 1 unit increase in an environmental attribute. For dichotomous measures of PA (not meeting vs. meeting the guidelines), GAMMs with binomial variance and logit link functions were used. The reported antilogarithms of the regression coefficients of these models represent odds ratios of meeting vs. not meeting the guidelines. Additionally, we estimated between-site differences in perceived environmental attributes adjusted for administrative-unit-level SES (a design variable) and socio-demographics. These models were used to estimate site-specific marginal means and their 95% CIs for each of the environmental predictors.

Main-effect GAMMs estimated the dose-response relationships of all perceived environmental attributes with the continuous and categorical PA outcomes, adjusting for study site, socio-demographic covariates, administrative-unit-level SES, and accelerometer wear time (hereafter named ‘covariates’). Covariate-adjusted single-environmental-variable and full-environmental-variable (all perceived environmental variables entered) GAMMs were estimated. All environmental variables could be simultaneously entered in GAMMs as collinearity was not a problem (variance inflation factor<2). For all main effects, a two-tailed probability level of 0.05 was adopted. Curvilinear relationships of perceived environmental attributes with outcomes were estimated using smooth terms in GAMMs, which were modeled using thin-plate splines (40). 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 perceived environmental attributes by study site interaction effects. 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 (5). Significant interaction effects were probed by computing the site-specific association.

To examine the extent to which perceived environmental attributes contributed to between-site differences in PA outcomes, marginal proportions and means of PA outcomes (as appropriate), adjusted and unadjusted for perceived environmental attributes (but all adjusted for other covariates), were estimated for each study site. We then calculated the proportional difference in variance between site-specific environment-unadjusted and environment-adjusted estimates of PA outcomes. These statistics represented the proportion of between-site variance in PA outcomes explained by differences in perceived environmental attributes. Site-specific differences between the environment-unadjusted and -adjusted estimates of PA outcomes were also computed along with their significance level. A statistically significant difference indicated that the perceived neighborhood environment in a specific site contributed significantly to the observed level of PA of that site (*NB*: no causal effects are implied). A positive difference (higher environment-unadjusted than -adjusted mean/proportion) would denote site-level beneficial effects of the environment on PA, while a negative difference would be indicative of deleterious environmental effects. Patterns of perceived environmental attributes by sites showing deleterious, nil, and beneficial environmental effects on PA were then examined to identify the environmental characteristics that contributed to the overall site-level environmental effects.

As there were less than 5% of cases (4.19%; n=305) with missing data, analyses were performed on complete cases (21). Participants with complete data were more likely to be males (p=.012), employed (p=.033), hold a tertiary degree (p=.033), have more valid hours of accelerometer wear time per day (p=.001) and live in neighborhoods perceived to have higher levels of street connectivity (p=.004), aesthetics (p=.022) and land use mix – diversity (p=.008). To examine the potential effect of using different types of accelerometers on the regression estimates, all GAMMs were run with and without data from New Zealand. As the two sets of analyses produced very similar results (<4% difference in regression coefficients), we report findings based on all available data (including data from New Zealand). All analyses were conducted in R.

Results

Patterns of perceived environmental attributes and physical activity outcomes

Table 2 shows the overall and site-specific means and standard deviations of the perceived environmental attributes, while the full circles in Figure 1 represent the point estimates of site-specific average daily minutes of MVPA and proportions of respondents meeting the PA guidelines for cancer/weight gain prevention adjusted for socio-demographic and other non-environmental covariates. PA outcomes and perceived environmental attributes varied substantially across sites (Table 1 and Figure 1). With the exception of Bogota (Colombia), the American sites and Ghent (Belgium) ranked lower on both PA outcomes, while Pamplona (Spain), Hong Kong (China), Olomouc (Czech Republic) and two New Zealand sites (North Shore and Wellington) ranked consistently higher (Figure 1). The ranking of sites according to perceived environmental attributes was less regular and only in part mirroring that of the PA outcomes (Table 2).

Associations of perceived environmental attributes with physical activity outcomes and between-site differences in associations

The single-environment-variable models identified six to seven significant perceived environmental correlates of PA outcomes (Table 3). Land use mix – access, land use mix – diversity, street connectivity, pedestrian infrastructure and safety, and aesthetics were significantly ($p \leq .05$) positively related to both PA outcomes. In the full-environmental-variable models (Table 3), two to three correlates remained statistically significant, and another one approached statistical significance ($p \leq .100$). These models accounted for 1.2% within-site variance in MVPA, corresponding to a standard deviation of ~3 min/day or ~21 min/week of MVPA.

Perceived aesthetics (p=.049), land use mix – access (p<.001) and, marginally, land use mix – diversity (p=.100) independently contributed to the explanation of average daily minutes of MVPA. The relationship with land use mix – access was curvilinear, whereby the strength of the association with MVPA increased starting from medium levels (score of 2.5 on the scale) of this attribute (Figure 2). Significant study site by street connectivity and aesthetics interaction effects were observed. Specifically, perceived street connectivity was positively associated with average daily minutes of MVPA in Curitiba – Brazil (e^b=1.139; 95% CI: 1.022, 1.270; p=.019), Bogota – Colombia (e^b=1.198; 95% CI: 1.004, 1.430; p=.046) and Aarhus – Denmark (e^b=1.192; 95% CI: 1.030, 1.378; p=.019), and negatively associated with MVPA in Waitakere – New Zealand (e^b=0.822; 95% CI: 0.697, 0.968; p=.020). Higher aesthetics was predictive of higher MVPA in Seattle - USA (e^b=1.070; 95% CI: 1.002, 1.141; p=.043) and Baltimore – USA (e^b=1.164; 95% CI: 1.081, 1.254; p<.001), but lower MVPA in Ghent – Belgium (e^b=0.919; 95% CI: 0.853, 0.990; p=.027). No other interaction effects of study site were observed.

Aesthetics and safety from crime were predictive of higher odds of meeting the PA guidelines for cancer and weight gain prevention. However, their effects were weaker than that of land use mix – access. No significant interaction effects of study sites were observed. Environmental attributes accounted for 1.3% variance in prevalence meeting the PA guidelines, corresponding to a standard deviation of ~4.5% people meeting the guidelines.

Contribution of perceived environmental attributes to between-site differences in physical activity outcomes

Substantial between-site differences in PA outcomes were observed when both adjusting and not adjusting for perceived neighborhood environment (Figure 1). The percentage of site-level variance in PA outcomes attributable to perceived neighborhood environment attributes was 15.9% for average daily minutes of MVPA and 16.8% for probability of meeting the PA guidelines for cancer and weight gain prevention. These represent moderate effect sizes (12).

Perceived environmental attributes contributed significantly to the between-site variability in average daily minutes of MVPA with respect to Cuernavaca (Mexico), Stoke-on-Trent (UK) and Pamplona (Spain) (Figure 1). The first two sites had perceived environments that were less PA-friendly than the overall sites' average. Thus, after adjusting for environmental perceptions, their PA levels (triangles point down in Figure 1) were higher than the environment-unadjusted PA levels (solid circles in Figure 1). The opposite was true for Pamplona. If all between-site variability in daily minutes of MVPA could be attributed to the perceived environment, the environment-adjusted estimates of MVPA represented by the triangles in Figure 1 would be placed on a straight vertical line (denoting no between-site variability in MVPA).

The perceived environment also contributed significantly to the between-site differences in the proportion of participants meeting the PA guidelines for cancer/weight gain prevention with respect to 9 of the 16 sites (Figure 1). It was estimated that it impacted negatively on the proportion of people meeting the guidelines in Bogota (Colombia), Cuernavaca (Mexico), North Shore, Waitakere, and Christchurch (NZ), but had a positive impact on those living in Aarhus (Denmark), Hong Kong (China), Pamplona (Spain) and Seattle (USA).

Figure 3 shows the patterns of perceived neighborhood environment attributes by study sites grouped by (i) deleterious, (ii) non-significant and (iii) beneficial site-level effects of environmental attributes on meeting the PA guidelines for cancer/weight gain prevention (NB: results for daily minutes of MVPA are not presented as they were similar to those of meeting the PA guidelines). All environmental attributes somewhat differed across sites with different site-level environmental effects. In contrast to the pooled within-site analyses, the strongest effects were found for residential density, pedestrian infrastructure/safety, crime safety, and few cul-de-sacs. Higher levels of these attributes were associated with more positive environmental effects on PA.

Discussion

Perceived land use mix – access and diversity, street connectivity, pedestrian infrastructure and safety, aesthetics, safety from crime, few cul-de-sacs, and lack of barriers to walking were all positively associated with the PA outcomes in the site-adjusted, single-predictor models. However, only 2 to 3 of these showed independent effects in the multiple-predictor models, indicating a substantial amount of shared variance amongst the environmental correlates (9). For example, neighborhoods with high levels of land use mix tend to have better pedestrian infrastructure and be more interconnected, making it then difficult to assess the independent contributions of each of these particular attributes to PA.

Except for perceived aesthetics and street connectivity, the observed associations were generalizable across all study sites. Perceived land use mix – access showed the strongest positive curvilinear and linear relationships with average daily minutes of MVPA and the odds of meeting the PA guidelines for cancer/weight gain prevention, respectively. The curvilinear relationship with average daily minutes of MVPA (Figure 2) is indicative of a possible threshold effect whereby facilitative effects of perceived land use mix on PA would be found only at medium to high levels of access to a variety of land uses. Land use mix, indicating proximity between homes and common destinations like shops, facilitates walking for transportation, which is likely the mechanism for the strong associations reported here. The fact that associations of perceived aesthetics and street connectivity with MVPA varied across study sites might have been due to participants from different sites engaging in different types of PA. For example, while perceived aesthetics may be an important correlate of PA for sites where a substantial amount of PA is accumulated through leisure activities (e.g., recreational walking or jogging), street connectivity may be more relevant to sites where transportation-related PA is a greater contributor to PA. This proposition would need to be explored in future analyses of environmental correlates of both total and domain/context specific PA.

Perceived environmental attributes were related to the proportion of populations across sites meeting the ambitious PA recommendations for preventing weight gain and cancers (420 minutes per week). The current lack of information on potential environmental contributors to reducing the risk of these two major global health problems makes this an important finding. Our results suggest that, with the exception of safety from crime, objectively-measured average daily minutes of MVPA and odds of meeting the PA recommendations for cancer and weight/gain prevention share similar perceived environmental correlates. Perceived safety from crime appears to be important for achieving quite high (420+ minutes weekly) rather than lower levels of PA or, alternatively, adults engaging in quite high levels of PA may tend to perceive their neighborhood environment as safer than do their less active counterparts.

Perceived environmental attributes contributed to the explanation of between-site differences in PA outcomes, with the strongest effects being observed for meeting the PA guidelines for cancer and weight gain prevention. The greatest differences in perceived environmental attributes amongst sites showing deleterious, nil, or beneficial environmental effects on PA were observed for safety-related attributes, residential density, and few cul-de-sacs. In other words, these perceived attributes were the most relevant contributors to the observed between-site differences in the proportion of populations meeting the PA guidelines for cancer and weight gain prevention. Yet, over 80% of between-site differences in meeting the PA guidelines could not be explained by perceived environmental factors.

In line with this study, perceived (as well as objective) land use mix – access has been previously identified as one of the most consistent correlates of total self-reported PA (13,32) and transport-related PA (11,14,34,35). It has also been linked, although less consistently, to higher levels of leisure-time PA (9,35). Perceived land use mix – access appears to substantially contribute to total amounts of PA in countries where walking is highly prevalent (e.g., Hong Kong, Spain and Colombia), but also in countries where a high proportion of the total amount of PA is accumulated through leisure-time vigorous activities (USA and New Zealand) (2). This neighborhood attribute is deemed to promote walking by providing a range of different types of easily-accessible destinations and services catering to residents' daily needs. Land use mix is usually the result of zoning codes that define the legal uses of land. Thus, zoning reform is a means of changing land use mix, which could be expected to impact PA in all the countries studied here. Aesthetics-related features (e.g., tree-lined streets, parks and green areas where residents can exercise) are believed to contribute to total PA by encouraging engagement in active leisure-time pursuits (30), which appear to be particularly prevalent in the USA (2). This would in part explain why in this and previous studies (33,34) aesthetics and PA were more consistently and strongly associated in the USA than other countries (35).

We found much smaller differences in associations across sites compared to a recent multi-site study based on self-report measures (13). Our use of a cross-validated, comparable measure of perceived environmental attributes and objective rather than self-report measures of PA might explain the discrepancies. Previously-observed heterogeneity in associations might have been mainly due to methodological and cultural factors (i.e., differences in interpretation of survey items and response biases) rather than substantive differences. Our study provides preliminary evidence that the potential impact of some aspects of the perceived built environment on PA might be generalizable to various geographical regions and cultures across the world.

Whilst previous international studies based on pooled or single-site data showed inconsistent and, sometimes, unexpected relationships of neighborhood residential density and safety aspects with PA (13,30,34,35), in the present study these perceived attributes were the best at explaining between-site differences in PA. It appears that the perceived environmental factors that contribute to between- vs. within-site differences in PA differ. Residential density and safety aspects of the environment may act more as macro-level influences, while aesthetics and land use mix may be attributes that can have pronounced effects at smaller geographical scales (within localities). At this stage, we can only speculate on the reasons underlying the observed results. It is possible that differences may be in part due to the levels of within- and between-site variability in perceived neighborhood attributes. Specifically, the average scores on perceived safety from crime and residential density varied quite substantially across study sites, while this was not the case for perceived aesthetics and land use mix (Table 2).

Strengths and limitations of the study

To inform environment- and policy-focused international and national strategies for the promotion of PA, comparable and good quality international data collected across geographical locations varying in exposure and outcome measures are needed. Using data from 16 cities across 5 continents, the present study aimed to contribute to this essential body of knowledge by providing findings on pooled and, where appropriate, site-specific associations of perceived neighborhood environmental attributes with objectively-measured PA outcomes (25). This is the first multi-country study to examine perceived environment-PA associations using an objective measure of PA, which is ‘immune’ to cultural bias. Single-site and site-adjusted pooled analyses do not provide information on differences in site-level environment-PA associations. Consequently, this was the first study to also estimate the extent to which perceived environmental characteristics explained between-site differences in PA and identified patterns of characteristics that might be responsible for these. This is also the first study to provide insight into perceived environmental correlates of meeting the PA guidelines for cancer and weight gain prevention, representing two major global public health issues (36,37).

Although this study addressed a series of methodological issues present in earlier investigations, there were some limitations. First, samples were not designed to be representative of the respective study sites and thus could not provide valid population-estimates of average daily minutes of MVPA and prevalence of meeting the PA guidelines for cancer/weight gain prevention. The sampling strategy adopted was designed to maximize the within-site variability in exposures and outcomes with the aim of increasing the statistical power to detect associations and estimate dose-response relationships. Second, the number of participants by study site varied substantially, resulting in relatively greater weights given to data from sites with larger sample sizes. However, the observed associations were, on the whole, generalizable across sites indicating that the different sample sizes did not significantly impact the significance and direction of associations. Third, the number of study sites was relatively small compared to the number of environmental attributes examined. Because study sites represented a small convenience sample of cities, they were not treated as a random factor in the single- and multiple-predictor models. Thus, we could not simultaneously estimate and separate between-site from within-site environmental effects on PA outcomes. Fourth, despite efforts to standardize methods, the response rates, survey methods, and type of accelerometers somewhat varied across sites. This may imply different sampling biases and other biases of a methodological nature across study sites. Yet, the fact that associations were rather homogenous across sites is reassuring. Fifth, accelerometers do not take into account the domain and contextual aspects of PA (e.g., walking for transport versus walking for recreation; engagement in PA within- versus outside the neighborhood), which would have helped better understand the findings. Yet, from a public health perspective, it is important also to identify factors that may contribute to higher levels of total PA, as increases in a specific PA domain and context (e.g., walking for transport within the neighborhood) may be followed by decreases in other PA domains and contexts (e.g., vigorous leisure-time PA outside the neighborhood) due to compensatory mechanisms. Sixth, some differences in socio-demographics and perceived environmental variables were identified between participants wearing and not-wearing accelerometers. However, these differences were small and their correlates were accounted for in the regression models to address possible biases arising from differences between wearers and non-wearers. Further, the study did not include some important macro-level environmental predictors of PA that might have explained a substantial proportion of between-site differences in PA outcomes (e.g., climatic conditions and car ownership) (4). It is possible that some of the observed between-site residual differences in PA outcomes were due to slight differences in the recruitment strategies and survey administration and/or accelerometer deployment methods employed by the local participating research teams (25). Also, some residual variance might have been caused by perceptions of the neighborhood environment representing relative rather than absolute measures of the environment. In other words, respondents' ratings of their own neighborhood environment are based on the range of objective variation in the environmental attributes to which they have been exposed. These between-site differences in interpretation of response scales would attenuate between-site associations of perceived environmental attributes with PA. If this is the case, objective measures of the neighborhood environment and PA would permit a more accurate assessment of environment-PA associations at the site level and identification of environmental attributes that may be responsible for between-site differences in PA.

Conclusions

This study suggests that there may be a global definition for perceived activity-supporting environments that may contribute to the accumulation of health-enhancing levels of PA, which are typified by high levels of perceived land use mix, street connectivity, residential density, aesthetics, pedestrian infrastructure, and safety. This raises the possibility that implementing environmental changes can have similar effects across many countries and support international recommendations to create more activity-friendly environments (38). Residents' perceptions of the neighborhood environment may be particularly important for supporting the accumulation of the higher levels of PA engagement that are recommended for cancer/weight gain prevention.

Relatively large between-site differences in PA outcomes were observed. Perceived environmental features accounted for moderate amounts of variance in PA outcomes across countries, whilst 80% of the between-site variance was unexplained. Residential density, pedestrian infrastructure, and safety from crime emerged as particularly important potential contributors to inter-site differences in PA. They represent candidate features for large-scale multi-sectoral interventions.

Future studies will need to establish whether some of the unaccounted between-site variance in physical activity could be attributed to using self-report rather than objective measures of the neighborhood environment. Other areas of improvement would be the inclusion of a larger number of diverse study sites, the recruitment of a relatively balanced number of participants across sites, the addition of other potentially-important macro-level environmental correlates of PA (e.g., meteorological conditions and air pollution), and an analysis of the extent to which objective and perceived measures of the neighborhood environment yield similar findings. The latter analysis would help evaluate issues of possible reverse causation, whereby observed associations between perceptions of the neighborhood environment and PA would arise from more active residents sharing more favorable views about their neighborhood.

Acknowledgments

All authors declare financial support for the submitted work from the National Cancer Institute of the National Institutes of Health. Data collection in Hong Kong was supported by the HK Research Grants Council GRF grants (#HKU740907H and #747807H) and HKU URC Strategic Research Theme (Public Health). US data collection and Coordinating Center processing was supported by the NIH grants R01 HL67350 (NHLBI) and R01 CA127296 (NCI). The study conducted in Bogota was funded by Colciencias grant 519_2010, Fogarty and CeiBA. The contributions of Neville Owen were supported by NHMRC Program Grant #569940, NHMRC Senior Principal Research Fellowship #1003960, and by the Victorian Government's Operational Infrastructure Support Program. The Danish study was partly funded by the Municipality of Aarhus. Data collection in the Czech Republic was supported by the grant MEYS (# MSM 6198959221). Data collection in New Zealand was supported by the Health Research Council of New Zealand grant # 07/356. Data collection in Mexico was supported by the CDC Foundation which received a training grant from The Coca-Cola Company. The UK study was funded by the Medical Research Council under the National Preventive Research Initiative. Deborah Salvo received a research grant from the CDC Foundation. Olga L Sarmiento received a research grant from the Coca Cola Company outside of submitted work. Kelli L Cain is a consultant for Santech, Inc. James F Sallis received grants and personal fees from the Robert Wood Johnson Foundation outside of submitted work, grants and non-financial support from Nike, Inc. outside of submitted work, is a Santech, Inc. shareholder and is a consultant and receiver of royalties from SPARK Programs of School Specialty, Inc. The results of the present study do not constitute endorsement by the ACSM.

References

1. Aparicio-Ting FE, Friedenreich CM, Kopciuk KA, Plotnikoff RC, Bryant HE. Prevalence of meeting physical activity guidelines for cancer prevention in Alberta. Chronic Dis Inj Can. 2012; 32:216–226. [PubMed: 23046804]
2. Bauman A, Bull F, Chey T, et al. The international prevalence study on physical activity: results from 20 countries. Int J Behav Nutr Phys Act. 2009; 6:21. 2009. [Internet]. Available from: http://www.ijbnpa.org/content/6/1/21. [PubMed: 19335883]
3. Bauman AE, Reis RS, Sallis JF, et al. Correlates of physical activity: why are some people physically active and others not? Lancet. 2012; 380:258–271. [PubMed: 22818938]
4. Bosdriesz JR, Witvliet MI, Visscher TLS, Kunst AE. The influence of the macro-environment on physical activity: a multilevel analysis of 38 countries worldwide. Int J Behav Nutri Phys Act. 2012; 9:110. [Internet]. Available from: http://www.ijbnpa.org/content/9/1/110.

5. Burnham, KP.; Anderson, DR. Model Selection and Multimodel Inference: A Practical Information-Theoretic Approach. 2nd ed.. New York (NY): Springer; 2002. p. 488
6. Cain, K. Accelerometer Scoring Protocol for the IPEN-Adult Study. San Diego (CA): University of California, San Diego; [Internet] Available from: http://www.ipenproject.org/documents/methods_docs/IPEN_Protocol.pdf [[cited 2013 Nov 5]]
7. Cerin E, Conway TL, Cain KL, et al. Sharing good NEWS across the world: developing comparable scores across 12 countries for the neighborhood environment walkability scale (NEWS). BMC Public Health. 2013; 13:309. [Internet]. Available from: http://www.biomedcentral.com/1471-2458/13/309. [PubMed: 23566032]
8. Cerin E, Leslie E, Bauman A, Owen N. Levels of physical activity for colon cancer prevention compared with generic public health recommendations: population prevalence and socio-demographic correlates. Cancer Epidemiol Biomarkers Prev. 2005; 14:1000–1002. [PubMed: 15824178]
9. Cerin E, Leslie E, Owen N, Bauman A. An Australian version of the neighborhood environment walkability scale: construct and factorial validity. Meas Phys Educ Exerc Sci. 2008; 12:31–51.
10. Cerin E, Saelens BE, Sallis JF, Frank LD. Neighborhood environment walkability scale: validity and development of a short form. Med Sci Sports Exerc. 2006; 38:1682–1691. [PubMed: 16960531]
11. Cerin E, Sit CHP, Barnett A, Johnston JM, Cheung MC, Chan WM. Aging in an ultra-dense metropolis: perceived neighbourhood characteristics and utilitarian walking in Hong Kong elders. Public Health Nutr. 2014; 17:225–232. [PubMed: 22906505]
12. Cohen, J. Statistical Power Analysis for the Behavioral Sciences. 2nd ed.. Hillsdale (NJ): Lawrence Erlbaum Associates; 1988. p. 567
13. Ding D, Adams MA, Sallis JF, et al. Perceived neighborhood environment and physical activity in 11 countries: do associations differ by country? Int J Behav Nutr Phys Act. 2013; 10:57. [Internet]. [PubMed: 23672435]
14. Ewing R, Cervero R. Travel and the built environment: a meta-analysis. J Am Plann Assoc. 2010; 76:265–294.
15. Frank LD, Sallis JF, Saelens BE, Leary L, Cain K, Conway TL, Hess PM. The development of a walkability index: application to the neighborhood quality of life study. Br J Sports Med. 2010; 44:924–933. [PubMed: 19406732]
16. Freedson PS, Melanson E, Sirard J. Calibration of the computer science and applications, inc. accelerometer. Med Sci Sports Exerc. 1998; 30:777–781. [PubMed: 9588623]
17. Freedson PS, Miller K. Objective monitoring of physical activity using motion sensors and heart rate. Res Q Exerc Sport. 2000; 71:S21–S29. [PubMed: 10925821]
18. Gebel K, Bauman AE, Sugiyama T, Owen N. Mismatch between perceived and objectively assessed neighborhood walkability attributes: prospective relationships with walking and weight gain. Health Place. 2011; 17:519–524. [PubMed: 21233002]
19. Guthold R, Ono T, Strong KL, Chatterji S, Morabia A. Worldwide variability in physical inactivity: a 51-country survey. Am J Prev Med. 2008; 34:486–494. [PubMed: 18471584]
20. Hallal PC, Andersen LB, Bull FC, et al. Global physical activity levels: surveillance progress, pitfalls, and prospects. Lancet. 2012; 380:247–257. [PubMed: 22818937]
21. Harrell, FE. Regression Modeling Strategies: With Applications to Linear Models, Logistic Regression and Survival Analysis. New York (NY): Springer-Verlag; 2001. p. 567
22. Heath GW, Parra DC, Sarmiento OL, et al. Evidence-based intervention in physical activity: lessons from around the world. Lancet. 2012; 380:272–281. [PubMed: 22818939]
23. Hino AA, Reis RS, Sarmiento OL, Parra DC, Brownson RC. The built environment and recreational physical activity among adults in Curitiba, Brazil. Prev Med. 2011; 52:419–422. [PubMed: 21497165]
24. Kawachi, I.; Berkman, LF. Neighborhoods and Health. New York (NY): Oxford University Press; 2003. p. 352
25. Kerr J, Sallis JF, Owen N, et al. Advancing science and policy through a coordinated international study of physical activity and built environments: IPEN adult methods. J Phys Act Health. 2013; 10:581–601. [PubMed: 22975776]

26. Kohl HW, Craig CL, Lambert EV, et al. The pandemic of physical inactivity: global action for public health. Lancet. 2012; 380:294–305. [PubMed: 22818941]
27. Lee IM, Djoussé L, Sesso HD, Wang L, Buring JE. Physical activity and weight gain prevention. JAMA. 2010; 303:1173–1179. [PubMed: 20332403]
28. Lee IM, Shiroma EJ, Lobelo F, et al. Effect of physical inactivity on major non-communicable diseases worldwide: an analysis of burden of disease and life expectancy. Lancet. 2012; 380:219–299. [PubMed: 22818936]
29. Pollard TM, Guell C. Assessing physical activity in Muslim women of South Asian origin. J Phys Act Health. 2012; 9:970–976. [PubMed: 22971888]
30. Saelens BE, Handy S. Built environment correlates of walking: a review. Med Sci Sports Exerc. 2008; 40:550–566.
31. Saelens BE, Sallis JF, Black JB, Chen D. Neighborhood-based differences in physical activity: an environment scale evaluation. Am J Public Health. 2003; 93:1552–1558. [PubMed: 12948979]
32. Sallis JF, Bowles HR, Bauman A, et al. Neighborhood environments and physical activity among adults in 11 countries. Am J Prev Med. 2009; 36:484–490. [PubMed: 19460656]
33. Shigematsu R, Sallis JF, Conway TL, et al. Age differences in the relation of perceived neighborhood environment to walking. Med Sci Sports Exerc. 2009; 41:314–321. [PubMed: 19127195]
34. Van Dyck D, Cerin E, Conway TL, et al. Perceived neighborhood environmental attributes associated with adults' leisure-time physical activity: findings from Belgium, Australia and the USA. Health Place. 2013; 19:59–68. [PubMed: 23178650]
35. Van Holle V, Deforche B, Van Cauwenberg J, Goubert L, Maes L, Van de Weghe N, De Bourdeaudhuij I. Relationship between the physical environment and different domains of physical activity in European adults: a systematic review. BMC Public Health. 2012; 12:807. [Internet]. Available from: http://www.biomedcentral.com/1471-2458/12/807. [PubMed: 22992438]
36. World Cancer Research Fund and American Institute for Cancer Research. Food, Nutrition, Physical Activity and the Prevention of Cancer: A Global Perspective. Washington, DC: American Institute for Cancer Research; 2007. p. 15Available from: AICR, Washington.
37. World Health Organization. Obesity: Preventing and Managing the Global Epidemic. Geneva, Switzerland: World Health Organization; 2000. p. 265Available from: WHO, Geneva.
38. World Health Organization. Global Strategy on Diet, Physical Activity and Health. Geneva, Switzerland: World Health Organization; 2004. p. 21Available from: WHO, Geneva.
39. World Health Organization. Global Recommendations on Physical Activity for Health. Geneva, Switzerland: World Health Organization; 2010. p. 582010. Available from: WHO, Geneva.
40. Wood, SN. Generalized Additive Models: An Introduction with R. Boca Raton (FL): Chapman and Hall; 2006. p. 392

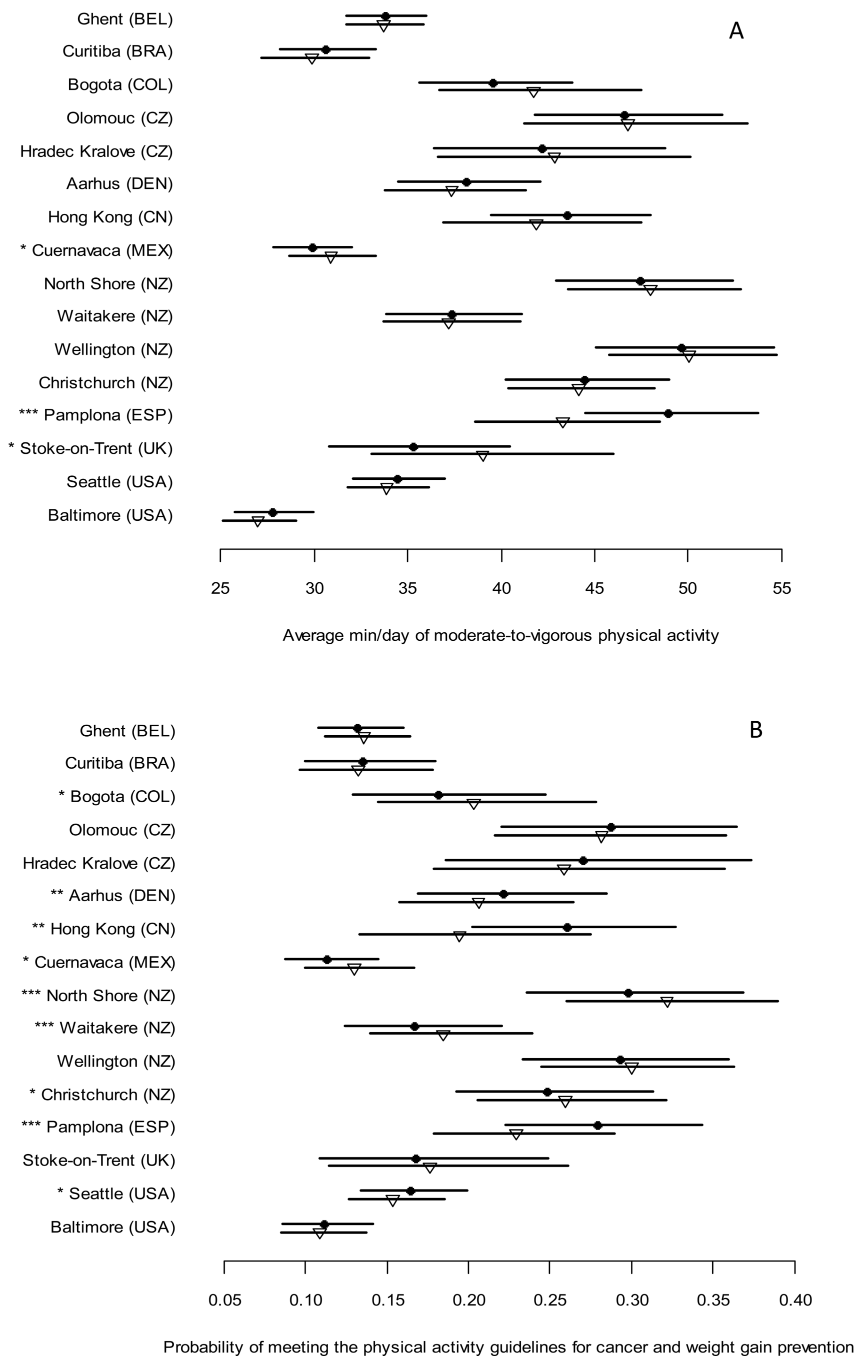

Figure 1. Site-specific average accelerometry-based moderate-to-vigorous physical activity (A) and probability of meeting the physical activity guidelines for cancer/weight gain prevention (B) unadjusted (—●—) and adjusted (▽) for perceived environmental attributes

*p<.05, ** p<.01, ***p<.001 indicate significant differences between site-specific environment-unadjusted and -adjusted marginal means of daily minutes of moderate-to-vigorous physical activity (panel A) and probabilities of meeting the cancer/overweight prevention physical activity guidelines (panel B).

Environment-adjusted estimates were estimated at pooled average levels of perceived environmental attributes. All estimates were adjusted for administrative-unit level socio-economic status, socio-demographic characteristics, and accelerometer wear time. Bars denote 95% confidence intervals.

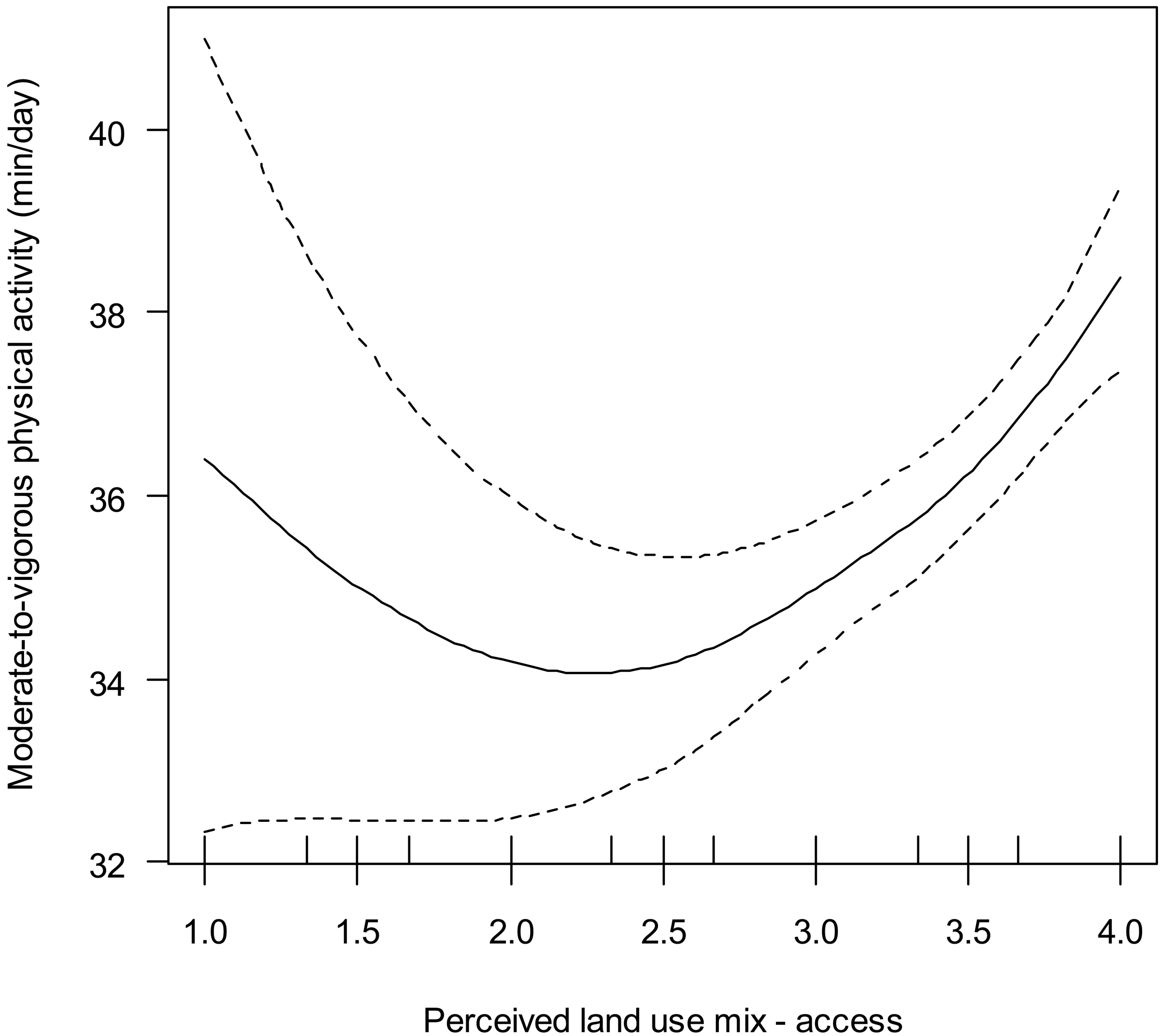

Figure 2. Non-linear relationship between perceived land use mix - access and average accelerometer-based moderate-to-vigorous physical activity

The solid line represents point estimates (and dashed line their 95% confidence intervals) of average daily minutes of moderate-to-vigorous physical activity at various levels of perceived land use mix – access. These estimates were computed at average values of other environmental variables and covariates.

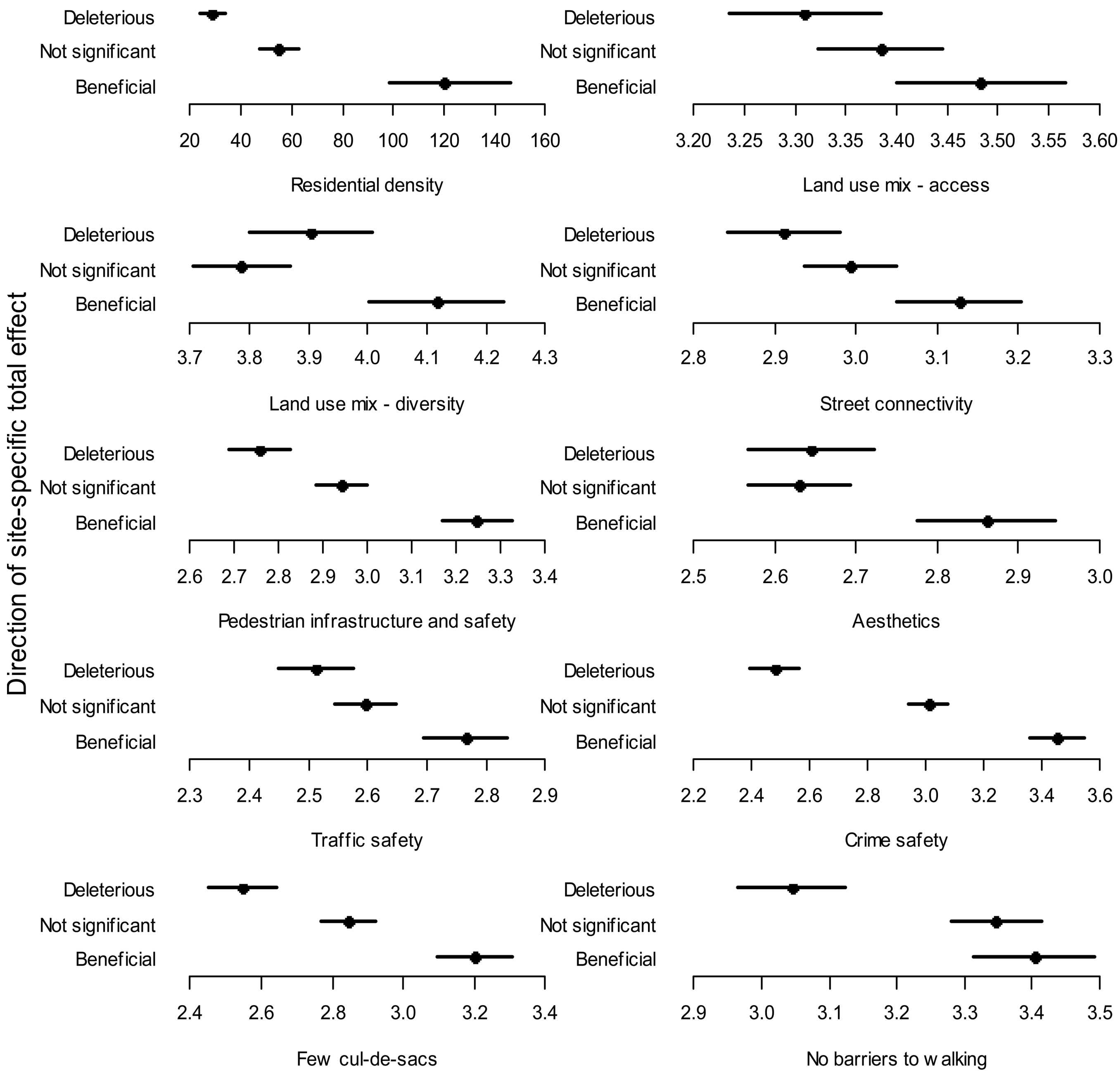

Figure 3. Mean and 95% CIs of perceived environmental attributes grouped by study sites with deleterious, non-significant (none), and beneficial total effects of perceived environmental attributes on the probability of meeting the physical activity guidelines for cancer and weight gain prevention

Sites with deleterious total environmental effects: Bogota (COL), Cuernavaca (MEX), North Shore (NZ), Waitakere (NZ), Christchurch (NZ). Sites with non-significant total environmental effects: Ghent (BEL), Curitiba (BRA), Olomouc (CZ), Hradec Kralove (CZ), Wellington (NZ), Stoke-on-Trent (UK), Baltimore (USA). Sites with beneficial total environmental effects: Aarhus (DEN), Hong Kong (CN), Pamplona (ESP), Seattle (USA).

Table 1

Sample characteristics: socio-demographic and accelerometer-based physical activity (PA) outcomes

	N with ≥4day valid PA data (% sample)	Age	Sex	Education			Work status	Marital status	Accelerometer wear time		PA outcome	
		Years	Men	Less than HS	HS graduate	College or more	Working	Couple	Valid days	Average wear (hrs/day)	MVPA min/day	PAG for cancer & weight gain prevention
Site	n (%)	M (SD)	%	%	%	%	%	%	M (SD)	M (SD)	M (SD)	%
All	7,273 (51)	43 (12)	45.9	12.1	38.4	49.5	78.8	64.3	6.5 (1.1)	14.4 (1.3)	38.0 (26.8)	19.7
Ghent (BEL)[1]	1,050 (99)	43 (13)	48.5	4.3	32.7	62.9	80.3	73.4	6.7 (1.1)	14.7 (1.3)	35.5 (23.5)	15.5
Curitiba (BRA)[2]	330 (47)	42 (13)	48.5	27.9	31.2	40.9	79.4	60.3	6.7 (1.0)	14.0 (1.3)	31.5 (24.6)	13.9
Bogota (COL)[2]	223 (23)	46 (12)	31.8	46.6	36.3	17.0	60.5	61.4	6.6 (1.0)	13.9 (1.2)	37.0 (26.4)	16.1
Olomouc (CZ)[1]	258 (78)	39 (14)	36.0	23.0	43.5	33.5	77.9	60.3	6.2 (1.2)	13.9 (1.4)	47.1 (27.7)	29.8
Hradec Kralove (CZ)[1]	122 (73)	36 (14)	38.6	15.7	56.5	27.8	82.8	52.6	6.2 (1.4)	14.2 (1.3)	45.1 (25.9)	29.5
Aarhus (DEN)[2]	272 (42)	40 (14)	39.0	7.4	42.3	50.4	75.4	69.1	7.0 (0.8	14.9 (1.1)	39.7 (23.2)	24.3
Hong Kong (CN)[2]	269 (56)	42 (13)	40.5	36.4	23.1	40.5	62.7	56.1	5.9 (1.0	14.4 (1.4)	44.9 (25.3)	27.5
Cuernavaca (MEX)[1]	656 (97)	42 (13)	45.7	43.9	28.8	27.3	71.5	64.8	5.7 (1.0	14.0 (1.4)	31.2 (25.2)	12.3
North Shore (NZ)[1]	373 (73)	43 (12)	37.4	2.4	58.3	39.3	76.4	71.1	6.4 (1.3	14.2 (1.2)	45.7 (28.4)	27.9
Waitakere (NZ)[1]	399 (78)	42 (11)	40.4	3.8	64.7	31.6	86.2	76.1	6.4 (1.3	14.1 (1.3)	37.2 (29.2)	16.3
Wellington (NZ)[1]	416 (84)	40 (12)	47.6	0.5	45.0	54.6	87.5	60.1	6.7 (1.3	14.0 (1.2)	50.1 (31.0)	30.0
Christchurch (NZ)[1]	373 (75)	43 (12)	45.6	8.6	57.0	34.4	85.5	57.1	6.5 (1.3	14.0 (1.2)	44.0 (32.5)	25.2
Pamplona (ESP)[2]	329 (36)	39 (13)	39.5	4.3	32.7	63.0	76.3	57.3	6.5 (0.8	15.0 (1.1)	51.0 (29.5)	31.3
Stoke-on-Trent (UK)[2]	135 (16)	44 (13)	46.7	38.8	46.3	14.9	64.4	45.9	6.6 (1.0	14.6 (1.2)	36.7 (27.3)	19.3
Seattle (USA)[1]	1198 (93)	44 (11)	55.0	1.1	34.9	64.0	81.4	64.1	6.7 (0.8	14.7 (1.3)	36.3 (24.9)	18.9
Baltimore (USA)[1]	870 (95)	47 (11)	48.7	1.8	29.6	68.5	83.0	61.1	6.7 (1.2	14.8 (1.4)	29.2 (22.0)	12.9

N and n = number of participants; HS = high school; MVPA = moderate-to-vigorous physical activity. PAG = physical activity guidelines. Valid days of accelerometer wear are those with 10+ valid hours of wear. BEL = Belgium; BRA = Brazil; COL = Colombia; CZ = Czech Republic; DEN = Denmark; CN = China; MEX = Mexico; NZ = New Zealand; ESP = Spain; UK = the United Kingdom; USA = the United States of America.

NIH-PA Author Manuscript

NIH-PA Author Manuscript

[1]Study site aimed to collect accelerometer data on the whole sample.

[2]Study site aimed to collect data on a fixed proportion of the total sample.

Table 2

Means (standard deviations) of perceived environmental attribute for the total sample and by study site (N=7,273)

	Perceived environmental attributes (theoretical range)									
Site	**Residential density (0–1000)**	**Land use mix – access (1–4)**	**Land use mix – diversity (1–5)**	**Street connectivity (1–4)**	**Infrastructure and safety (1–4)**	**Aesthetics (1–4)**	**Traffic safety (1–4)**	**Crime safety (1–4)**	**Few cul-de-sacs (1–4)**	**No major barriers to walking (1–4)**
All	74.6 (112.7)	3.3 (0.7)	3.8 (0.8)	3.0 (0.7)	2.9 (0.6)	2.8 (0.7)	2.6 (0.6)	3.1 (0.7)	2.8 (1.0)	3.3 (0.8)
Ghent (BEL)	82.6 (72.6)	3.3 (0.6)	3.6 (0.9)	2.7 (0.7)	2.8 (0.5)	2.6 (0.6)	2.4 (0.6)	3.2 (0.5)	3.0 (0.8)	3.3 (0.7)
Curitiba (BRA)	99.7 (123.6)	3.6 (0.5)	4.1 (0.5)	3.3 (0.7)	2.8 (0.8)	2.9 (0.8)	2.4 (0.8)	2.3 (0.5)	2.9 (1.1)	3.1 (1.1)
Bogota (COL)	51.7 (59.6)	3.4 (0.4)	4.2 (0.4)	3.1 (0.6)	2.8 (0.5)	2.4 (0.5)	2.4 (0.5)	1.9 (0.6)	2.7 (0.8)	2.9 (0.7)
Olomouc (CZ)	89.1 (68.6)	3.5 (0.6)	3.9 (0.6)	3.0 (0.7)	3.1 (0.5)	2.4 (0.6)	2.9 (0.6)	3.2 (0.6)	2.9 (1.0)	3.4 (0.8)
Hradec Kralove (CZ)	85.1 (68.8)	3.4 (0.6)	4.0 (0.6)	3.0 (0.6)	3.2 (0.5)	2.6 (0.5)	3.1 (0.5)	3.4 (0.5)	3.0 (0.9)	3.5 (0.8)
Aarhus (DEN)	83.5 (63.4)	3.6 (0.6)	4.2 (0.6)	3.1 (0.6)	3.1 (0.5)	2.7 (0.6)	2.9 (0.5)	3.3 (0.6)	2.8 (0.9)	3.7 (0.6)
Hong Kong (CN)	443.8 (216.2)	3.5 (0.7)	4.1 (0.7)	3.2 (0.8)	3.4 (0.6)	2.8 (0.7)	2.9 (0.6)	3.4 (0.6)	3.5 (0.8)	3.3 (1.0)
Cuernavaca (MEX)	38.1 (40.9)	3.3 (0.5)	3.7 (0.6)	2.9 (0.5)	2.6 (0.4)	2.6 (0.5)	2.4 (0.5)	2.2 (0.7)	2.6 (0.7)	2.8 (0.7)
North Shore (NZ)	30.0 (49.9)	3.2 (0.6)	3.8 (0.6)	2.7 (0.5)	2.8 (0.3)	2.8 (0.5)	2.6 (0.5)	3.1 (0.5)	2.3 (0.6)	3.3 (0.6)
Waitakere (NZ)	19.1 (26.4)	3.1 (0.5)	3.7 (0.7)	2.7 (0.4)	2.8 (0.4)	2.9 (0.5)	2.6 (0.5)	2.9 (0.4)	2.3 (0.6)	3.2 (0.6)
Wellington (NZ)	45.5 (65.5)	3.4 (0.5)	4.1 (0.6)	2.8 (0.5)	2.9 (0.4)	2.8 (0.5)	2.8 (0.4)	3.1 (0.4)	2.5 (0.7)	3.3 (0.5)
Christchurch (NZ)	22.7 (26.7)	3.4 (0.5)	3.9 (0.6)	3.0 (0.5)	3.0 (0.4)	2.8 (0.6)	2.7 (0.5)	2.9 (0.6)	2.5 (0.8)	3.5 (0.7)
Pamplona (ESP)	187.0 (102.3)	3.7 (0.5)	4.5 (0.4)	3.3 (0.7)	3.4 (0.5)	2.7 (0.7)	2.5 (0.7)	3.6 (0.6)	3.6 (0.9)	3.6 (0.8)
Stoke-on-Trent (UK)	36.2 (32.5)	3.4 (0.7)	3.7 (0.5)	3.1 (0.7)	3.2 (0.5)	2.3 (0.8)	2.5 (0.7)	3.0 (0.7)	2.3 (1.0)	3.4 (0.8)
Seattle (USA)	37.5 (53.9)	3.2 (0.8)	3.8 (0.8)	3.0 (0.8)	3.0 (0.6)	3.1 (0.7)	2.7 (0.7)	3.4 (0.6)	2.8 (1.1)	3.2 (1.0)
Baltimore (USA)	59.9 (79.4)	3.0 (0.8)	3.6 (0.9)	3.0 (0.8)	3.1 (0.6)	3.1 (0.6)	2.7 (0.7)	3.4 (0.7)	2.8 (1.2)	3.8 (0.6)

BEL = Belgium; BRA = Brazil; COL = Colombia; CZ = Czech Republic; DEN = Denmark; CN = China; MEX = Mexico; NZ = New Zealand; ESP = Spain; UK = the United Kingdom; USA = the United States of America

Table 3

Pooled associations of perceived environmental attributes with physical activity (PA) outcomes (N= 6,968)

Environmental attribute	Model	Moderate-to-vigorous PA (min/day)[a]			Meeting the PA guidelines for cancer and weight gain prevention[b]		
		exp(b)	exp(95% CI)	p	OR	95% CI	p
Residential density	SEV	1.001	(1.000, 1.001)	.096	1.001	(1.000, 1.001)	.085
	FEV	***1.000***	***(0.999, 1.000)***	***.476***	***1.001***	***(1.000, 1.001)***	***.196***
Land use mix –access (linear)	SEV	1.027	(0.960, 1.098)	.439	1.266	(1.138, 1.409)	<.001
Curvilinear		F(2.82, 2.82) = 16.07		<.001	-	-	-
Linear	***FEV***	***1.015***	***(0.956, 1.077)***	***.806***	***1.168***	***(1.029, 1.326)***	***.010***
Curvilinear		***F(2.53, 2.53) = 7.98***		***<.001***	-	-	-
Land use mix – diversity	SEV	1.056	(1.030, 1.082)	<.001	1.137	(1.030, 1.254)	.011
	FEV	***1.024***	***(0.996, 1.054)***	***.100***	***1.017***	***(0.908, 1.140)***	***.772***
Connectivity	SEV	1.043	(1.018, 1.069)	<.001	1.190	(1.079, 1.312)	<.001
	FEV	***1.013***	***(0.987, 1.041)***	***.325***	***1.093***	***(0.983, 1.217)***	***.102***
Pedestrian infrastructure and safety	SEV	1.054	(1.021, 1.087)	.001	1.192	(1.052, 1.351)	.006
	FEV	***1.005***	***(0.970, 1.041)***	***.797***	***1.018***	***(0.885, 1.171)***	***.804***
Aesthetics	SEV	1.049	(1.019, 1.079)	.001	1.188	(1.065, 1.326)	.002
	FEV	***1.030***	***(1.000, 1.061)***	***.049***	***1.132***	***(1.010, 1.270)***	***.033***
Traffic safety	SEV	1.022	(0.995, 1.050)	.109	1.081	(0.971, 1.200)	.145
	FEV	***1.001***	***(0.973, 1.029)***	***.956***	***1.009***	***(0.903, 1.128)***	***.870***
Safety from crime	SEV	1.027	(0.998, 1.058)	.068	1.165	(1.039, 1.306)	.009
	FEV	***1.017***	***(0.987, 1.049)***	***.266***	***1.143***	***(1.013, 1.288)***	***.030***
Few cul-de-sacs	SEV	0.996	(0.978, 1.014)	.643	1.071	(1.000, 1.154)	.050
	FEV	***0.988***	***(0.970, 1.007)***	***.207***	***1.052***	***(0.978, 1.131)***	***.174***
No major barriers to walking	SEV	1.033	(1.012, 1.055)	.002	1.050	(0.967, 1.140)	.249
	FEV	***1.016***	***(0.994, 1.038)***	***.158***	***0.986***	***(0.905, 1.073)***	***.740***

SEV = single-environmental-variable. FEV = full-environmental-variable. Linear = linear regression term. Curvilinear = curvilinear regression term. OR = odds ratio; 95% CI = 95% confidence intervals; exp(b) = antilogarithm of regression coefficient; exp(95% CI) = antilogarithm of confidence intervals; - = not applicable.

All regression coefficients are adjusted for respondents' age, sex, marital status, educational attainment, employment status, administrative-unit socio-economic status, and accelerometer wear time.

[a] generalized additive mixed model (GAMM) with Gamma variance and logarithmic link functions, for which exp(b) is to be interpreted as the proportional increase in PA associated with a 1 unit increase on the predictor.

[b]GAMM binomial variance and logit link functions.

NIH-PA Author Manuscript
NIH-PA Author Manuscript