Van Dyck D, Cerin E, Conway TL, De Bourdeaudhuij I, Owen N, Kerr J, Cardon G, Frank LD, Saelens BE, Sallis JF. Perceived neighborhood environmental attributes associated with adults' leisure-time physical activity: findings from Belgium, Australia and the USA. Health Place 2013;19:59-68.

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Perceived neighborhood environmental attributes associated with adults' leisure-time physical activity: Findings from Belgium, Australia and the USA

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ABSTRACT

The study purpose was to examine the strength, direction and shape of the associations of environmental perceptions with recreational walking and leisure-time moderate-to-vigorous physical activity, using pooled data from four study sites (Baltimore [USA], Seattle [USA], Adelaide [Australia] and Ghent [Belgium]). Moreover, site- and gender-specificity of the associations were examined. In total, 6,014 adults (20-65 years, 55.7% women) completed the Neighborhood Environmental Walkability Scale and the International Physical Activity Questionnaire. Both a 'recreational walking-friendliness' index and a 'leisure-time activity friendliness' index had a positive linear association with recreational walking and leisure-time moderate-to-vigorous physical activity respectively. The associations were significant in all study sites except Ghent. Present findings were clearly site-specific, imposing possible challenges for built environment recommendations. In Europe, interventions to promote leisure-time activity may need to target promotion of existing opportunities rather than built environment improvements.

Key words: leisure-time, exercise, built environment, policy

INTRODUCTION

A large proportion of the adult populations of developed countries does not engage in sufficient physical activity to gain health benefits out of it (United States Department of Health and Human Services, 2008). Since physical inactivity is associated with elevated risk of major chronic diseases, interventions to promote healthy and active lifestyles need to be developed and implemented (Garber et al., 2011). In that context, ecological models of health behaviors emphasize the importance of taking into account multiple levels of influence when developing interventions. In addition to individual and social attributes, built environment and policy factors are expected to affect physical activity in different domains (e.g. transport or leisure) and different settings (e.g. neighborhoods, parks) (Sallis et al., 2008).

A growing body of evidence shows that objective and perceived built environment factors are positively associated with physical activity in adults (Brownson et al., 2009; Butler et al., 2011; Heath et al., 2006; Sundquist et al, 2011; Wendel-Vos et al., 2007; Wong et al., 2011). However, built environment correlates are behavior-specific and the factors associated with leisure-time physical activity are less understood than those associated with active transportation. Proximity to recreation facilities and aesthetic-related features have been consistently related to leisure-time physical activity (Cerin et al., 2008a; Kondo et al., 2009; Owen et al., 2004; Van Dyck et al., 2011), but the role of other environmental variables, such as residential density, the availability of walking and cycling infrastructures, crime, and traffic safety is less understood (Inoue et al., 2010; Kondo et al., 2009; Saelens & Handy, 2008; Titze et al, 2010; Van Dyck et al., 2011).

Most previous studies of associations of built-environment attributes with physical activity have been conducted in one or perhaps two regions and nearly all are from single countries. Furthermore, with the exception of a few recent African and Latin American studies (Gomes et al, 2011; Oyeyemi et al, 2011; Parra et al, 2011), most previous studies have been conducted in the USA, Australia and Europe. Limited within-region, within-country and between-country variability in built environment attributes and physical activity levels can potentially contribute to an underestimation of strength of associations. Findings from multiple regions and countries are needed to provide a wider range of variability, which will better inform national and regional policies shaping communities and to develop international guidelines for improving built environments to stimulate 'active living'.

A recent study combined data from 11 environmentally-diverse countries to examine perceived environmental correlates of overall physical activity, using common methods, and found several environmental variables to be linearly and positively related to meeting activity guidelines (Sallis et al., 2009a). Associations were stronger than those reported in single-country studies, probably because data from multiple countries provides a wider range of environmental variability. To gain further insight in the strength, shape and directions of the associations between built environment characteristics and health behaviors, we recently examined the relationship between environmental perceptions and sitting time in four study sites in three diverse countries (USA, Australia and Belgium), using common protocols and pooled analyses (Van Dyck et al, 2012). Site- and gender-specific associations between perceived environmental attributes and overall sitting time were found and the relationship between perceived land-use mix and motorized transport was curvilinear.

Based on these promising findings and the added value to be gained by conducting built environment studies in multiple regions/countries using the same methods, we conducted the present analyses on pooled data from the same three countries. We examined the strength, direction and shape of the associations of environmental perceptions with leisure-time activity (recreational walking and leisure-time moderate-to-vigorous physical activity). In addition, we examined whether these associations differed by study site and gender. We chose to focus specifically on leisure-time physical activity, because the built-environment correlates of this type of physical activity remain unclear (Wendel-Vos et al., 2007).

METHODS

Procedures and Participants

Data from three countries (four study sites) were pooled for present analyses: USA (Neighborhood Quality of Life Study [NQLS] in Seattle-King County and Baltimore-Washington DC regions), Australia (Physical Activity in Localities and Community Environments [PLACE] study in Adelaide), and Belgium (Belgian Environmental Physical Activity Study [BEPAS] in Ghent). Detailed information on the protocols, procedures and other results of these three studies can be found elsewhere (Owen et al., 2007; Sallis et al., 2009b; Van Dyck et al., 2010).

Briefly, in each country, participants (20-65 year old adults) were recruited in high- and low-walkable and high- and low-income neighborhoods (32 neighborhoods in NQLS and PLACE; 24 neighborhoods in BEPAS). The neighborhoods were chosen to maximize within-country variance in walkability and income. In all countries, neighborhoods consisted of clusters of administrative units (block groups in USA; Census Collectors' Districts in Australia; statistical sectors in Belgium). These administrative units were the smallest geographical units for which information on income and other demographic factors was available.

Neighborhood-level walkability was determined objectively, using a Geographic Information Systems (GIS) based walkability index, including three (BEPAS) or four (NQLS and PLACE) environmental attributes previously found to be related to physical activity (Frank et al., 2010): net residential density, land use mix, intersection density, and retail floor area ratio. Retail floor area ratio was not available for BEPAS. A detailed description of the calculation of the walkability index is given elsewhere (Frank et al., 2010). To determine neighborhood-level income, census-based median annual household income data were used (Australian Bureau of Statistics, 2001; National Institute of Statistics – Belgium, 2007; United States Census Data, 2000). The neighborhood selection procedure resulted in an equal number of neighborhoods (n=8 for NQLS and PLACE; n=6 for BEPAS) among four types, stratified as follows: high-walkable/high-income, high-walkable/low-income, low-walkable/high-income, and low-walkable/low-income.

In the USA, NQLS data collection took place between May 2002 and June 2005. In total, 8,504 adults living in the 32 neighborhoods were randomly selected from lists supplied by a marketing company, contacted by phone and mailed a survey if they agreed to participate. In total, 2,199 participants completed the mailed survey (response rate = 25.9%; 1,287 participants in Seattle and 912 participants in Baltimore). Response rates did not differ significantly by study quadrant (range from 23% to 29%). In Australia, PLACE data collection was conducted between July 2003 and June 2004. A simple random sampling procedure was used to select possible participants from residential locations identified within the 32 selected neighborhoods. Invitation letters and surveys were mailed to each residence. In total, residents from 2,650 of the 23,128 identified addresses returned a completed survey (response rate = 11.5%). Response rates did not differ significantly by study quadrant (range from 10.5% to 12.8%). In Belgium, BEPAS data collection took place between May 2007 and September 2008. In each neighborhood, 250 randomly selected adults received an invitation letter and were visited at home two-to-six days after posting the letter. Recruitment continued until 50 participants per neighborhood were recruited (response rate = 58.0%); 1,165 adults participated in BEPAS. Response rates did not differ significantly by study quadrant (range from 57.5% to 58.7%). In all studies, data were collected throughout the year to take seasonal variation into account.

All participants completed a written informed consent form. NQLS was approved by Institutional Review Boards at participating academic institutions, PLACE was approved by the Behavioral and Social Sciences Ethics Committee of the University of Queensland, and BEPAS was approved by the Ethics Committee of the Ghent University Hospital.

Measures

Environmental perceptions: To measure perceived neighborhood built- and social-environmental factors, the Dutch and English versions of the previously validated Neighborhood Environmental Walkability Scale (NEWS) were used (Cerin et al., 2008a; De Bourdeaudhuij et al., 2003; Saelens et al., 2003). Before data analysis, comparability of the NEWS items across the three countries was assessed by two independent raters and only comparable NEWS items were analyzed. Scales and items were selected according to their conceptual relevance to recreational walking and leisure-time moderate-to-vigorous physical activity. Neighborhood environment scales included in the analyses were residential density (5 items), a land use mix-diversity scale potentially relevant to recreational walking (6 items on proximity to parks, recreational/fitness facilities and shops; only included in the analyses with recreational walking as outcome measure), land use mix-diversity items potentially relevant to leisure-time moderate-to-vigorous physical activity (2 items on parks and recreational/fitness facilities; named proximity to recreation facilities and only included in the analyses with leisure-time moderate-to-vigorous physical activity as outcome measure), walking and cycling facilities (6 items), aesthetics (3 items), traffic safety (3 items), and crime safety (3 items). Additionally, a single item was used: 'there are many barriers in my neighborhood which make it difficult to walk from one place to the other'. Calculation of these NEWS sub-scales employed methods proposed by Cerin and colleagues (2009) based on cross-validation of the factor structure of the NEWS (see http://www.drjamessallis.sdsu.edu/measures.html; NEWS-CFA scoring procedure). All environmental items were rated on a four-point scale (1-4 from *strongly disagree* to *strongly agree*), except for residential density (five-point scale; 1-5) and land use mix-diversity (1-4 from more than 30 minutes to 1-5 minutes) . In the analyses, all scales and the single item of NEWS were treated as continuous variables. Site-specific descriptive statistics of the NEWS scales can be found in Table 1.

Physical activity: Self-reported physical activity was measured with the International Physical Activity Questionnaire (IPAQ; long, past seven days version). Physical activity assessed by the IPAQ showed good reliability (intra-class correlations range from .46 to .96) and fair-to-moderate criterion validity compared against accelerometers (median ρ=.30) in a 12-country study (Craig et al., 2003). Frequency (number of days in the last seven days) and duration (minutes/day) of physical activity in different domains were queried. Based on this information, separate estimates of weekly minutes of recreational walking and non-walking leisure-time moderate-to-vigorous physical activity were calculated. To allow other forms of physical activity to be controlled for, weekly minutes (with no weighting for intensity) were calculated for work-, household- and transport-related physical activity. In Belgium, the interviewer-administered version of IPAQ was used, while in Australia and the USA, participants completed the self-administered version.

Socio-demographic information: Self-reported socio-demographic variables included gender, age, marital status (partner vs. no partner), educational level (college/university degree vs. no college/university degree), and body mass index (calculated from height and weight).

Data analytic plan

Descriptive statistics (means, standard deviations, percentages, and percentage of missing values) were computed by study site for all variables. The strength and shape of the associations of perceived environmental attributes with weekly minutes of recreational walking and leisure-time moderate-to-vigorous physical activity were estimated using generalized additive mixed models (GAMMs) (Wood, 2006) with negative binomial variance and logarithmic link functions. GAMMs can model positively-skewed physical activity data, account for dependency in error terms due to clustering (observations sampled from selected neighborhoods), and estimate complex, dose-response relationships of unknown form (Wood, 2006). A first set of models estimated the dose-response relationships of single perceived environmental attributes (six scales and one single item; continuous variables) with the two physical activity outcomes, adjusting for study site, socio-demographic covariates and total weekly minutes of work-, household- and transport-related physical activity. Separate models were run to estimate main effects of environmental attributes, and all of the two-way and three-way gender by environmental attributes by study site interaction effects. All perceived environmental attributes with main and/or interaction effects significant at a 0.15 probability level were included in respective multiple-predictor models of recreational walking and leisure-time moderate-to-vigorous physical activity. The main and interaction terms that remained significant at a 0.15 probability level were retained in the final models.

Environmental variables significant at the 0.15 level in the multiple-predictor models were also used to construct two composite environmental indices (one continuous index for each outcome variable): a recreational walking-friendliness index and a leisure-time activity-friendliness index. These indices represented the sum of the standardized scores (z-scores, computed across all sites) for the variables that were linearly positively related with the outcome. For variables that showed a curvilinear relationship, z-scores were computed using appropriate polynomial functions best describing the relationship (in this study, the sum of the linear and quadratic values of a z-score weighted by their respective regression coefficients constrained so as to sum to 1, and derived from a GAMMs including a linear and a quadratic term for a predictor of interest). The dose-response relationships of these two indices with the relative outcomes also were estimated using GAMMs.

To address the problem of having approximately 18% of cases with missing values on at least one of the variables, 10 multiple imputed datasets were created, as recommended by Rubin (1987). Analyses on multiple imputed data yield unbiased estimates of regression coefficients if data are missing at random [28]. The point estimates of the regression coefficients derived from the imputed and complete-cases datasets were similar. However, multiple imputations yielded narrower confidence intervals. All analyses were conducted in R (R Development Core Team, 2011) using the packages 'car' (Fox & Weisberg, 2011), 'mgcv' (Wood, 2006) and 'Design' (Harrell, 2009).

RESULTS

Table 1 reports the descriptive statistics for each study site including region characteristics, sample socio-demographic characteristics, perceived environmental attributes, recreational walking, and leisure-time moderate-to-vigorous physical activity. The total sample consisted of 6,014 participants; 55.7% were women, 63.3% were living with a partner, and 55.4% had a college or university degree. Mean age of the total sample was 44.4 yrs (SD=11.9); mean body mass index (BMI) was 26.1 kg/m^2 (SD=5.5). Respondents from Ghent reported the lowest average levels of perceived land use mix, walking and cycling facilities, and aesthetics, but the highest level of residential density.

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Socio-demographic correlates of recreational walking and leisure-time moderate-to-vigorous physical activity

Table 2 reports the associations of socio-demographic covariates with weekly minutes of recreational walking and leisure-time moderate-to-vigorous physical activity. Belgian participants reported significantly fewer minutes of recreational walking than did participants from the other study sites and fewer minutes of leisure-time moderate-to-vigorous physical activity than residents of Seattle. Respondents from Seattle reported higher levels of recreational walking than did their Baltimore counterparts. Seattle participants also reported more minutes of moderate-to-vigorous physical activity than respondents from Adelaide. Having a lower BMI and having a college/university degree were linearly related to higher levels of recreational walking. Living in higher income areas, being male, being younger, having a college/university degree, and having a lower BMI were linearly predictive of higher levels of leisure-time moderate-to-vigorous physical activity. Age showed a curvilinear relationship with recreational walking. No association was found between age and recreational walking in those aged 18-35 years, but a positive association was found in those aged 35+ years.

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Dose-response associations between perceived physical environmental attributes and recreational walking

The single-predictor models of recreational walking showed positive associations with residential density, land use mix diversity, perceiving few barriers in the neighborhood, walking and cycling facilities, and aesthetics (Table 3). Significant curvilinear main effects were found for residential density and aesthetics (Fig. 1). Gender was a significant moderator of the relationships of recreational walking with aesthetics (curvilinear) and crime safety (linear), with women showing stronger (and different shaped for aesthetics) associations than men (Table 3 and Fig. 2). Associations with aesthetics, crime safety, and lack of barriers in the neighborhood were moderated by study site.

The multiple-predictor model of recreational walking yielded significant positive associations for residential density. The moderating effects of study site remained significant. Perceiving few barriers in the neighborhood was positively associated with recreational walking in Adelaide only, while Baltimore was the only site to show an independent positive association of aesthetics with walking (Table 3). Crime safety was predictive of less recreational walking in Ghent and Seattle, and more walking in Adelaide.

A recreational walking-friendliness index consisted of the sum of the standardized z-scores of perceived environmental attributes independently positively related (overall, within a site or socio-demographic subgroup) to recreational walking. These were residential density, aesthetics, and perceiving few barriers in the neighborhood. The index was linearly positively related to recreational walking, with one unit difference in the index being predictive of a 13.6% difference in walking minutes per week (95% CI: 8.9%, 18.5%). The associations of the recreational walking-friendliness index with walking varied by study site, with all sites but Ghent showing significant linear positive relationships (Table 3).

PLEASE INSERT TABLE 3 AND FIGURES 1-2 ABOUT HERE

Dose-response associations between perceived physical environmental attributes and leisure-time moderate-to-vigorous physical activity

In the single-predictor models, significant relationships existed between leisure-time moderate-to-vigorous physical activity and four out of seven environmental variables (Table 4). Walking and cycling facilities showed a curvilinear relationship (Fig. 3). Study site moderated the relationships of the physical activity outcome with perceived residential density, walking and cycling facilities, and crime safety (Table 4). Residential density tended to be positively associated with leisure-time moderate-to-vigorous physical activity in Seattle and Adelaide. For walking/cycling facilities, a positive association was only found in Adelaide, while crime safety was positively related to leisure-time moderate-to-vigorous physical activity only in Baltimore (Table 4).

In the final multiple-predictor model of leisure-time moderate-to-vigorous physical activity, the main effect of proximity to recreation facilities and the site by residential density, walking and cycling facilities, and crime safety interaction effects remained significant (Table 4).

PLEASE INSERT TABLE 4 AND FIGURE 3 ABOUT HERE

A composite leisure-time activity friendliness index consisted of the sum of the standardized z-scores of residential density, proximity to recreation facilities, walking and cycling facilities, and crime safety. This index was linearly positively related to leisure-time moderate-to-vigorous physical activity, with one unit difference in the index being predictive of a 10.7% difference in weekly minutes of leisure-time moderate-to-vigorous physical activity (95% CI: 4.9%, 16.9%). This association was significant in all sites with the exception of Ghent.

DISCUSSION

This study examined dose-response associations of perceived neighborhood environment attributes with self-reported leisure-time physical activity (walking and moderate-to-vigorous physical activity) in adults living in metropolitan areas in the USA, Australia and Belgium. After controlling for socio-demographic covariates and other types of physical activity, there were positive associations of neighborhood environment attributes with both outcome measures. Most associations showed evidence of a linear gradient, and important curvilinear effects and site-specific interactions were identified.

The ‘recreational walking-friendliness’ index included perceived residential density, aesthetics, and perceiving few barriers in the neighborhood towards walking. The ‘leisure-time activity friendliness’ index consisted of residential density, proximity of recreation facilities, walking and cycling facilities, and crime safety. Both indices were linearly positively associated with the outcome measures, but were only significant in Adelaide, Baltimore and Seattle, not in Ghent. For recreational walking, the multiple-predictor model revealed that residential density was the only attribute to be related to recreational walking across all study sites; aesthetics and perceiving few barriers in the neighborhood only explained recreational walking in Baltimore and Adelaide, respectively. For leisure-time moderate-to-vigorous physical activity, the multiple predictor model showed that all built environment correlates, with the exception of proximity to recreation facilities, were site-specific. Residential density contributed only in Adelaide and Seattle, while walking and cycling facilities and crime safety were only important in Adelaide and Baltimore, respectively.

Overall, correlates of the two leisure-time activity outcomes showed few similarities. Perceived residential density was the only factor to be included in both environmental indices. In previous studies, residential density has been found to be more related to active transportation (Cerin et al., 2008a; De Bourdeaudhuij et al., 2005, Van Dyck et al., 2011). However, some studies have also identified residential density as a correlate of recreational walking (Cerin et al., 2006; De Bourdeaudhuij et al., 2005; Shigematsu et al., 2009). Perhaps denser residential environments tend to create more visual interest and contribute to more people on the streets that provide a sense of safety, although this might only be the case when residential density is not too high. The presence of very high residential density possibly produces opposite effects.

Furthermore, aesthetic-related features and perceiving few barriers in the neighborhood were associated with recreational walking. Aesthetic-related features have been consistently associated with leisure-time activity in previous studies (Frank et al., 2006; Hoehner et al., 2005; Saelens & Handy, 2008; Shigematsu et al., 2009; Sugiyama et al., 2009). Perceiving few barriers in the neighborhood has not been examined as a separate feature before, but the item showed potential to be an environmental correlate of recreational walking. It would be useful to create more detailed measures of neighborhood barriers to explicate this finding.

Next to residential density, also proximity to recreational facilities, the availability of walking and cycling facilities and crime safety were associated with leisure-time moderate-to-vigorous physical activity. To date, proximity to recreation facilities has been consistently related to leisure-time moderate-to-vigorous physical activity (Cerin et al., 2008b; Cerin et al., 2010; Kamada et al., 2009; Van Dyck et al., 2011), but inconsistent evidence has been reported on the importance of the availability of walking and cycling facilities (Parra et al., 2011; Saelens & Handy, 2008; Van Dyck et al., 2011). In our study, this factor did contribute to explaining recreational walking and moderate-to-vigorous physical activity. Crime safety and traffic safety have not been supported as consistent correlates of leisure-time physical activity in Western countries, where overall safety is relatively high (Foster & Giles-Corti, 2008). That pattern was partially supported in present results, as traffic safety was not associated with the outcome measures. For crime safety, complex results were found in the present study. The multiple predictor models showed that perceiving high crime safety was only associated with more leisure-time moderate-to-vigorous physical activity in Baltimore, and that crime safety was not related to recreational walking in Baltimore, showed a positive association in Adelaide, but was negatively related to recreational walking in Ghent and Seattle. In mid- and low-income countries suffering from high crime rates and poor traffic safety, the perceptions of safety seem to be more consistently related to adults' utilitarian and leisure-time physical activity (Parra et al, 2010; 2011).

An important finding was that in Ghent, no associations of the composite indices with recreational walking and leisure-time moderate-to-vigorous physical activity could be identified. A possible explanation for this result could lie in the fact that adults living in Ghent perceived their environment as more dense and less aesthetically pleasing and perceived a lower availability of walking/cycling facilities than did participants from Adelaide, Seattle and Baltimore. The findings from the single-predictor models revealed a curvilinear shape in the associations of perceived residential density and aesthetics with recreational walking and in the associations of perceived availability of walking and cycling facilities with leisure-time moderate-to-vigorous physical activity . For residential density, the associations reached a plateau at higher levels of density, while for aesthetics and availability of walking and cycling facilities, the associations were weaker at lower levels of perceptions. Because adults living in Ghent were situated at the higher end of the continuum for perceived residential density and at the lower end for perceived aesthetics and perceived availability of walking/cycling facilities, the curvilinear shape of these associations could possibly explain the lack of significance for associations with the composite indices in Belgian participants. Moreover, Belgian adults reported less recreational walking than their USA and Australian counterparts and less leisure-time moderate-to-vigorous physical activity than adults in the USA, which could also have an impact on the strength of the associations. Specific cultural differences in environmental perceptions and physical activity habits might also play a role here. There could be differential response biases as well, though these are difficult to quantify. The present results need to be replicated in future studies before any definite conclusions can be drawn, but one general conclusion is that the associations between the built environment and recreational physical activity are complicated and probably different in European cities, which are typically denser and have distinct land use patterns compared with cities in the USA and Australia (Newman & Kenworthy, 1991). Perhaps the higher levels of active transportation in European countries like Belgium (mainly transport-related cycling; Pucher et al., 2010) reduce the perceived or actual need for leisure-time physical activity, thus making environmental supports for leisure-time physical activity less relevant.

The linear shape of the associations between the composite environment-attribute indices and the activity outcomes suggests that environmental changes across the entire range have the potential to increase leisure-time physical activity (both walking and moderate-to-vigorous physical activity). This finding is promising in that policy changes and interventions to improve the built environment may be expected to be effective. Relatively favorable environments for leisure-time physical activity may already be contributing to higher levels of these behaviors in countries like the USA or Australia. Overall, few gender interactions were found, so environmental strategies to increase recreational physical activity might be expected to be effective in both men and women.

However, increasing residential density in highly-dense cities like Ghent or cities in Latin-America (e.g. Bogota, Colombia) should probably not be encouraged. The curvilinear shape of the associations between residential density and recreational walking indicates that very high density seems not to be related to physical activity or might even act as a detrimental factor (Cervero et al, 2009). Furthermore, creating density in the absence of improved transit service and very high quality pedestrian and recreational environments can actually result in worse health outcomes through increased exposure to air pollution, noise, and traffic congestion (Marshall et al., 2009). Extremely high-density environments are not known as healthy places to live. Performance zoning is one tool that has been successfully employed in many regions to generate funding for the provision of amenities required to create high-quality pedestrian and recreational environments. This approach leverages increased payoff for developers who are allowed to increase density when they choose to invest in aesthetic improvements like street furniture and street trees, overcome pedestrian barriers, and improve transit service.

The main strength of this study was the inclusion of large samples of adults in four culturally- and environmentally diverse environments spanning three countries. Consequently, larger variation in objective built environment attributes and levels of recreational physical activity was achieved than single-country studies can provide. Within-region variability in environmental characteristics was also maximized by recruiting participants from high- and low-walkable communities in each study site. Physical activity and built environment attributes were assessed using reliable and valid questionnaires. Nonetheless, study limitations need to be acknowledged. First, small European adaptations were applied to the Belgian version of NEWS, so only a limited number of comparable built environment attributes could be included in the analyses. Second, systematic reporting biases could have occurred. Moreover, the between-country variance in environmental perceptions seemed limited, although considerable variability in objective characteristics does exist. The similar response patterns in the answers to NEWS indicate that environmental perceptions may be relative and influenced by overall built environment characteristics within a country. Third, a cross-sectional design was used, precluding the determination of causality. Fourth, the interviewer-administered IPAQ was used in Belgium, while the self-administered version was used in the USA and Australia. Given the evidence that adults tend to over-report their physical activity mainly when completing the self-administered IPAQ (compared with the interview-version; Rzewnicki et al., 2003), the present results may be biased. Fifth, the low response rates in the USA and Australia could have potentially introduced selection bias, though response rates were similar across neighborhood types in all countries. The response rate was higher in the Belgian study, possibly because participants were visited at home instead of receiving a mailed survey (Portney & Watkins, 2009).

In conclusion, few similarities were found between the built environment characteristics related to recreational walking and those related to leisure-time moderate-to-vigorous physical activity. Perceived residential density, aesthetic-related attributes and perceiving few barriers to walking were associated with recreational walking, while perceived residential density, proximity to recreation facilities, availability of walking and cycling facilities and crime safety were associated with leisure-time moderate-to-vigorous activity. The present findings were clearly site-specific, imposing possible challenges for future interventions. In European countries, programs to improve the built environment probably need to focus on other environmental attributes, such as quality of parks. Alternatively, interventions to increase physical activity in Europe may need to focus more on promoting use of existing opportunities or on physical activity domains other than recreational physical activity. In the USA and Australia, interventions targeting the environmental factors identified in this study, may have a significant impact. To improve our understanding of the complex relationship between the built environment and different physical activity domains, future research should include an even more diverse set of regions and countries to maximize environmental variation and examine the generalizability of results.

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CONFLICT OF INTEREST STATEMENT

The authors declare that they have no conflict of interest.

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Table 1

Site-specific descriptive statistics for all outcome variables, socio-demographic covariates, and explanatory variables

	Seattle – USA (n=1,287)	Baltimore – USA (n=912)	Adelaide – Australia (n=2650)	Ghent – Belgium (n=1,165)
Site regional characteristics				
Number of inhabitants	1,916,441	5,699,478	1,289,265	248,269
Area (km²)	55,506	25,210	1,827	156.2
Population density (inhabit/km²)	348.1	226.1	1295.0	1,589.0
Mean temperature January (°C)	4.5	2.7	23.1	3.1
Mean temperature July (°C)	18.4	27.6	11.4	17.7
Average precipitation/year (mm)	944.6	1065.3	500.0	820.0
Area/neighborhood characteristics				
Area level household income [mean (SD)]	USD 56,680 (19,912.2)	USD 59,930 (21,758.3)	AUD 38,080 (12,966.0)	EU19,610.0 (3,967.2)
High walkable areas participants (%)	50.6	49.2	48.6	50.0
High SES areas participants (%)	51.3	52.5	52.2	50.5
Sample socio-demographic characteristics				
Gender - % women	45.1	52.3	63.7	52.0
Age [mean (SD)]	44.0 (11.0)	46.6 (10.7)	44.5 (12.3)	42.7 (12.6)
Marital status - % with partner	63.1	60.1	60.3	73.0
Education - % tertiary education	63.0	67.2	45.5	60.3
Body mass index [mean (SD)]	26.6 (5.5)	27.2 (5.9)	26.2 (5.9)	24.3 (3.9)
Physical activity variables [mean (SD)]				
Min/week of recreational walking	113.2 (163.2)	103.2 (160.4)	119.7 (179.6)	76.5 (133.2)
Min/week of leisure-time MVPA	128.3 (211.1)	112.1 (204.7)	85.6 (171.0)	94.2 (156.6)
Min/week of other physical activity	912.6 (836.0)	957.5 (840.8)	1357.6 (1036.5)	631.6 (528.4)
Perceived physical environmental attributes [mean (SD)]				
Residential density	140.5 (49.6)	156.4 (58.2)	143.5 (46.1)	201.0 (79.8)
Land use mix diversity – proximity to destinations relevant to recreational				

walking	3.3 (1.0)	3.0 (1.0)	3.5 (0.9)	2.8 (1.1)
Land use mix diversity – proximity to recreation facilities	3.7 (1.1)	3.4 (1.2)	3.7 (0.8)	2.6 (1.2)
Not many barriers in neighborhood	3.2 (1.0)	3.7 (0.6)	3.6 (0.6)	3.3 (0.7)
Walking and cycling facilities	2.9 (0.7)	3.1 (0.6)	3.0 (0.5)	2.7 (0.5)
Aesthetics	3.2 (0.7)	3.2 (0.6)	3.2 (0.7)	2.5 (0.6)
Traffic safety	3.4 (0.6)	3.4 (0.7)	3.0 (0.8)	3.1 (0.6)
Crime safety	3.4 (0.6)	3.4 (0.7)	3.0 (0.8)	3.1 (0.6)

SD = standard deviation; USD = United Stated Dollar; AUD = Australian dollar; EU = Euro; MVPA = moderate-to-vigorous physical activity.

Note: all perceived environmental attributes were positively scored: higher score = more walkable. 18.36% of missing observations on at least one variable.

Table 2

Associations of socio-demographic covariates with recreational walking and leisure-time moderate-to-vigorous physical activity (MVPA)

	Recreational walking (min/wk)			Leisure-time MVPA (min/wk)		
Variables	exp(*b*)	exp (95% CI)	*p*	exp(*b*)	exp (95% CI)	*p*
Area-level household income (deciles)	1.001	0.983, 1.019	.931	1.044	1.021, 1.068	<.001
Gender (Men vs. Women)	1.018	0.940, 1.101	.668	0.814	0.739, 0.897	<.001
Age (yrs)						
Linear component	0.848	0.751, 0.958	.008	0.874	0.832, 0.918	<.001
Quadratic component	1.004	1.001, 1.007	.007	-		
Cubic component	1.000	1.000, 1.000	.012	-		
Marital status (without vs. with partner)	1.016	0.994, 1.105	.719	0.906	0.819, 1.003	.056
Tertiary education (no vs. yes)	1.117	1.025, 1.218	.012	1.238	1.115, 1.375	<.001
Body mass index (kg/m^2)	0.980	0.973, 0.988	<.001	0.967	0.959, 0.975	<.001
Study site (reference category: Ghent, Belgium)						
Seattle, USA	1.496	1.270, 1.763	<.001	1.358	1.113, 1.657	.003
Baltimore, USA	1.258	1.058, 1.496	.013	1.202	0.974, 1.482	.090
Adelaide, Australia	1.360	1.178, 1.569	<.001	0.976	0.820, 1.162	.783

Note. Associations are adjusted for all other socio-demographic covariates. All regression models used a negative binomial variance function and a logarithmic link function. Exp(*b*) antilogarithm of regression coefficient; exp(95% CI) = antilogarithms of the 95% confidence intervals of the regression coefficient; *p* = probability value. The antilogarithms of the regression coefficients represent the proportional increase (if exp(b) > 1.00) or decrease (if exp(b)<1.00) in the outcome variables associated with a unit increase in an explanatory variable.

Table 3

Associations of perceived environmental attributes with recreational walking (min/wk)

Variables	exp(*b*)	exp (95% CI)	*p*
Models with single environmental attributes			
Main effects			
Residential density (linear component)*	1.109	0.990, 1.244	.075
Residential density (curvilinear smooth)*	F(1.85)=13.72		<.001
Land use mix-diversity – proximity to destinations relevant to recreational walking (shops, park, recreational/fitness facilities)	1.087	1.040, 1.137	<.001
Not many barriers in neighborhood	1.070	1.016, 1.128	.011
Walking and cycling facilities	1.097	1.049, 1.148	.014
Aesthetics (linear component)*	1.040	0.915, 1.181	.552
Aesthetics (curvilinear smooth)*	F(2.27)=6.49		<.001
Traffic safety	0.997	0.954, 1.042	.895
Crime safety	1.042	0.995, 1.091	.079
Interaction effects			
Gender by Aesthetics (linear component)*			
Association in men	1.080	1.010, 1.154	.024
Association in women	1.014	0.837, 1.229	.886
Gender by Aesthetics (curvilinear smooth)*			
Association in men	F(1.00)=5.11		.024
Association in women	F(2.58)=6.25		<.001
Gender by Crime safety			
Association in men	1.017	0.868, 1.193	.831
Association in women	1.065	1.007, 1.126	.027
Site by Not many barriers in neighborhood			
Association in Ghent, Belgium	0.964	0.853, 1.089	.554
Association in Seattle, USA	1.018	0.931, 1.114	.689
Association in Baltimore, USA	1.039	0.885, 1.220	.637
Association in Adelaide, Australia	1.188	1.091, 1.292	<.001
Site by Aesthetics			
Association in Ghent, Belgium	0.919	0.826, 1.023	.125
Association in Seattle, USA	1.034	0.942, 1.135	.481
Association in Baltimore, USA	1.240	1.103, 1.394	<.001
Association in Adelaide, Australia	1.100	1.027, 1.179	.007
Site by Crime safety			
Association in Ghent, Belgium	0.848	0.753, 0.954	.006
Association in Seattle, USA	0.887	0.802, 0.981	.020
Association in Baltimore, USA	1.143	1.024, 1.276	.018
Association in Adelaide, Australia	1.130	1.064, 1.201	<.001
Model with multiple environmental attributes and interaction effects *			
Residential density	1.002	1.001, 1.003	<.001
Site by Not many barriers in neighborhood			
Association in Ghent, Belgium	1.001	0.883, 1.133	.993
Association in Seattle, USA	1.008	0.992, 1.102	.861

Association in Baltimore, USA	1.040	0.882, 1.225	.462
Association in Adelaide, Australia	1.183	1.091, 1.281	<.001
Site by Aesthetics			
Association in Ghent, Belgium	0.932	0.799, 1.087	.369
Association in Seattle, USA	1.094	0.954, 1.255	.197
Association in Baltimore, USA	1.353	1.132, 1.618	<.001
Association in Adelaide, Australia	1.072	0.968, 1.187	.183
Site by Crime safety			
Association in Ghent, Belgium	0.818	0.688, 0.972	.023
Association in Seattle, USA	0.841	0.729, 0.974	.021
Association in Baltimore, USA	1.105	0.939, 1.301	.228
Association in Adelaide, Australia	1.153	1.054, 1.260	.002
Models with composite environmental index of recreational walking-friendliness			
Main effects			
Index (Residential density + Not many barriers in neighborhood + Aesthetics)	1.136	1.089, 1.185	<.001
Interaction effects			
Site by Recreational walking-friendliness			
Association in Ghent, Belgium	1.040	0.953, 1.136	.331
Association in Seattle, USA	1.097	1.009, 1.192	.030
Association in Baltimore, USA	1.252	1.105, 1.417	<.001
Association in Adelaide, Australia	1.216	1.138, 1.298	<.001

Note. All models were adjusted for gender, age, living arrangements (with vs. without partner), tertiary education (yes vs. no), area household income (in deciles), body mass index, study site, and weekly minutes of other types of physical activity (household, work and transportation). All regression models used a negative binomial variance function and a logarithmic link function. Only significant interaction effects are presented. Exp(*b*) antilogarithm of regression coefficient; exp(95% CI) = antilogarithms of the 95% confidence intervals of the regression coefficient; *p* = probability value; * = final model including only predictors significant at p<.15. The antilogarithms of the regression coefficients represent the proportional increase (if exp(b) > 1.00) or decrease (if exp(b)<1.00) in average min/wk of recreational walking associated with a unit increase in a perceived environmental attribute.

Table 4

Associations of perceived environmental attributes with leisure-time moderate-to-vigorous physical activity (min/wk)

Variables	exp(*b*)	exp (95% CI)	*p*
Models with single environmental attributes			
Main effects			
Residential density	1.034	0.976, 1.096	.252
Proximity to recreation facilities	1.098	1.046, 1.154	<.001
Not many barriers in neighborhood	1.037	0.973, 1.105	.266
Walking and cycling facilities (linear component)*	1.053	0.897, 1.235	.529
Walking and cycling facilities (curvilinear smooth)*	F(2.29)=4.58		.007
Aesthetics	1.039	0.980, 1.101	.202
Traffic safety	0.956	0.906, 1.001	.098
Crime safety	1.047	0.990, 1.108	.107
Interaction effects			
Site by Residential density			
Association in Ghent, Belgium	0.957	0.873, 1.047	.342
Association in Seattle, USA	1.147	0.997, 1.319	.056
Association in Baltimore, USA	0.960	0.840, 1.096	.546
Association in Adelaide, Australia	1.132	1.017, 1.260	.024
Site by Walking and cycling facilities			
Association in Ghent, Belgium	0.920	0.799, 1.059	.246
Association in Seattle, USA	1.018	0.924, 1.122	.721
Association in Baltimore, USA	1.111	0.982, 1.257	.095
Association in Adelaide, Australia	1.104	1.018, 1.198	.017
Site by Crime safety			
Association in Ghent, Belgium	1.045	0.905, 1.206	.547
Association in Seattle, USA	1.017	0.899, 1.150	.790
Association in Baltimore, USA	2.803	1.254, 6.264	.012
Association in Adelaide, Australia	1.021	0.949, 1.100	.575
Model with multiple environmental attributes and interaction effects #			
Main effects			
Proximity to recreation facilities	1.098	1.043, 1.157	<.001
Interaction effects			
Site by Residential density			
Association in Ghent, Belgium	0.999	0.998, 1.001	.423
Association in Seattle, USA	1.003	1.000, 1.005	.072
Association in Baltimore, USA	1.000	0.997, 1.003	.913
Association in Adelaide, Australia	1.002	1.000, 1.005	.056
Site by Walking and cycling facilities			
Association in Ghent, Belgium	0.817	0.629, 1.060	.129
Association in Seattle, USA	1.174	0.862, 1.599	.309
Association in Baltimore, USA	1.347	0.960, 1.889	.085
Association in Adelaide, Australia	1.372	1.019, 1.848	.037
Site by Crime safety			

Association in Ghent, Belgium	1.054	0.911, 1.220	.476
Association in Seattle, USA	1.035	0.912, 1.175	.591
Association in Baltimore, USA	2.481	1.183, 5.207	.016
Association in Adelaide, Australia	0.923	0.760, 1.120	.417
Models with composite environmental index of leisure-time activity friendliness			
Main effects			
Index (Residential density + Proximity to recreation facilities + Walking and cycling facilities + Crime safety)	1.107	1.049, 1.169	<.001
Interaction effects			
Site by Index			
Association in Ghent, Belgium	1.021	0.912, 1.143	.718
Association in Seattle, USA	1.130	1.045, 1.222	.002
Association in Baltimore, USA	1.136	1.000, 1.285	.043
Association in Adelaide, Australia	1.125	1.000, 1.266	.049

Note. All models were adjusted for gender, age, living arrangements (with vs. without partner), tertiary education (yes vs. no), area household income (in deciles), body mass index, study site, and weekly minutes of other types of physical activity (household, work and transportation). All regression models used a negative binomial variance function and a logarithmic link function. Only significant interaction effects are presented. Exp(*b*) antilogarithm of regression coefficient; exp(95% CI) = antilogarithms of the 95% confidence intervals of the regression coefficient; *p* = probability value; * for significant curvilinear relationships, the significance of both linear component and curvilinear smooth are reported; $^{\#}$ = final model including only predictors significant at p<.15. The antilogarithms of the regression coefficients represent the proportional increase (if exp(b) > 1.00) or decrease (if exp(b)<1.00) in average min/wk of leisure-time moderate-to-vigorous physical activity associated with a unit increase in a perceived environmental attribute.

FIGURE CAPTIONS

Figure 1: Dose-response relationship of perceived neighborhood residential density (A) and environmental aesthetics (B) with weekly minutes of recreational walking

Figure 2: Dose-response relationship of perceived environmental aesthetics with weekly minutes of recreational walking by gender

Figure 3: Dose-response relationship of perceived walking/cycling facilities with weekly minutes of leisure-time moderate-to-vigorous physical activity (MVPA)

Figure 1

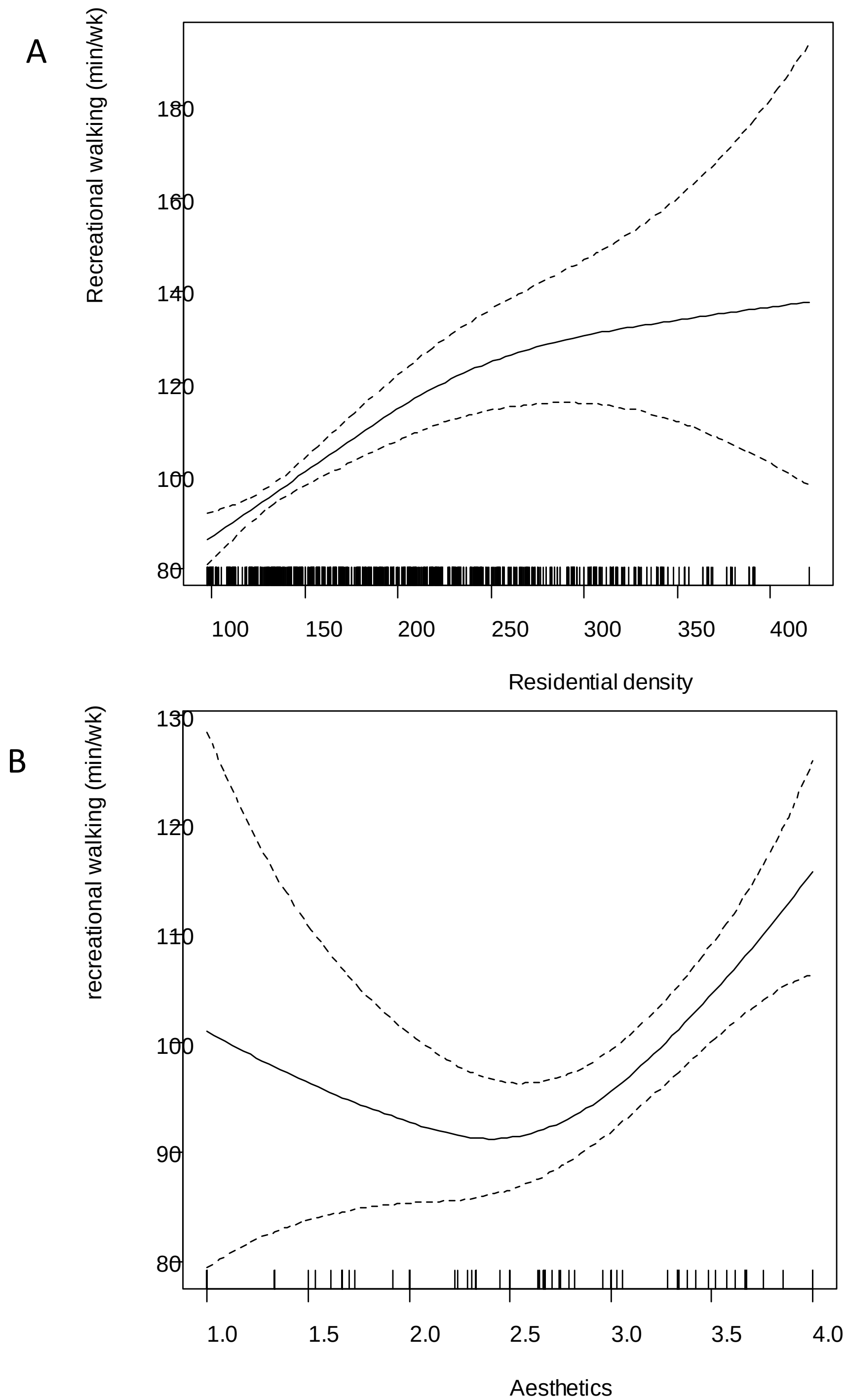
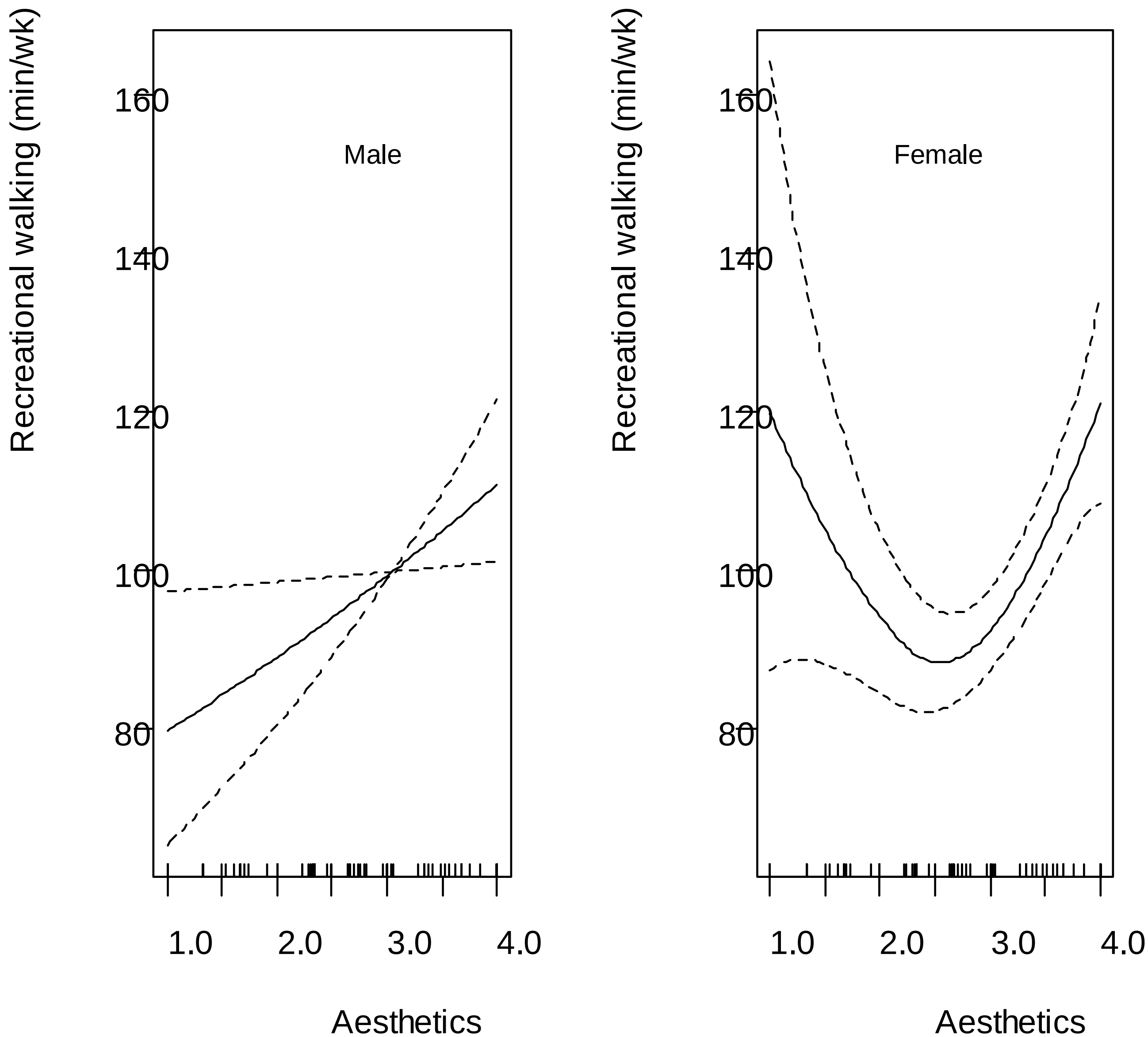
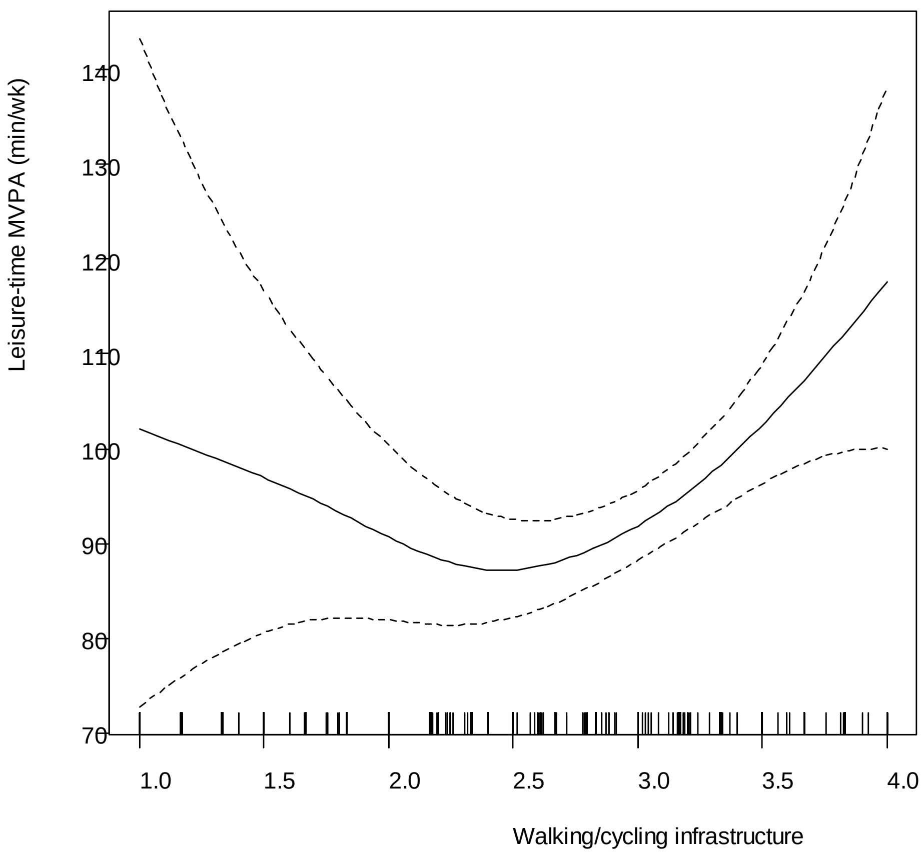

A
Recreational walking (min/wk)
80
100
120
140
160
180
100
150
200
250
300
350
400
Residential density
B
recreational walking (min/wk)
80
90
100
110
120
130
1.0
1.5
2.0
2.5
3.0
3.5
4.0
Aesthetics

Figure 2



Recreational walking (min/wk)
160
140
120
100
80
Male
1.0
2.0
3.0
4.0
Aesthetics
Recreational walking (min/wk)
160
140
120
100
80
Female
1.0
2.0
3.0
4.0
Aesthetics

Figure 3



Leisure-time MVPA (min/wk)
140
130
120
110
100
90
80
70
1.0
1.5
2.0
2.5
3.0
3.5
4.0
Walking/cycling infrastructure