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Original article

# Differences in transportation and leisure physical activity by neighborhood design controlling for residential choice

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**Abstract**

*Background*: Cross-sectional studies provide useful insight about the associations between the built environment and physical activity (PA), particularly when reasons for neighborhood choice are considered. Our study analyzed the relationship between levels of weekly transportation and leisure PA among 3 neighborhood designs, statistically adjusting for sociodemographic characteristics and reasons for neighborhood choice.

*Methods*: A stratified random sample of adults (age ≥20 years) living in Calgary (Canada) neighborhoods with different neighborhood designs (grid, warped-grid, and curvilinear) and socioeconomic status completed a self-administered questionnaire capturing PA, sociodemographic characteristics, and reasons for neighborhood choice (response rate = 10.1%; $n$ = 1023). Generalized linear models estimated associations between neighborhood design and transportation and leisure PA outcomes (participation (any *vs.* none) and volume (metabolic equivalent: h/week)), adjusting for neighborhood socioeconomic status, sociodemographic characteristics (gender, age, ethnicity, education, household income, marital status, children, vehicle access, dog ownership, and injury), and reasons for neighborhood choice (e.g., proximity and quality of recreational and utilitarian destinations, proximity to work, highway access, aesthetics, and sense of community).

*Results*: Overall, 854 participants had resided in their neighborhood for at least 12 months and provided complete data. Compared with those living in curvilinear neighborhoods, grid neighborhood participants had greater odds ($p < 0.05$) of participating in any transportation walking (odds ratio (OR) = 2.17), transportation and leisure cycling (OR = 2.39 and OR = 1.70), active transportation (OR = 2.16), and high-intensity leisure PA (≥6 metabolic equivalent; OR = 1.74), respectively. There were no neighborhood differences in the volume of any transportation or leisure PA undertaken. Adjustment for neighborhood selection had minimal impact on the statistical or practical importance of model estimates.

*Conclusion*: Neighborhood design is associated with PA patterns in adults, independent of reasons for neighborhood choice and sociodemographic factors.



**Keywords:** Active transportation; Built environment; Self-selection; Urban design; Walkability

## 1. Introduction

Urban planning decisions (e.g., regarding land use zoning, movement networks, public space, parks, trails, and topography) that affect the design or redesign of neighborhoods, towns, and cities have the potential to influence physical activity (PA), diet, and social interactions.[1] Notably, neighborhood design can enable and restrict PA in adults and can have varied effects on different types of PA (e.g., walking, cycling, and jogging) and its components (i.e., participation, duration, intensity, and volume).[2] However, not all types of PA necessarily are associated with the same built characteristics.[3−6] For instance, some neighborhood features (e.g., increased pedestrian and street connectivity, a high mix of destinations, higher residential densities, and increased availability of sidewalks) appear to be

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more positively associated with walking and cycling than with other types of PA.[2] These neighborhood features also appear to be more consistently associated with transportation PA (active modes including walking or cycling undertaken to get to and from destinations) than with leisure PA.[2]

Neighborhood-built environment interventions have the potential to increase, decrease, or result in no net change in PA. In a study involving U.S. adults, Brown et al.[7] found no difference in self-reported weekly minutes of moderate-to-vigorous PA (MVPA) among residents in 5 suburban neighborhoods (where there was residential land use only, with no apartments or condominiums, featuring curvilinear street patterns, many cul-de-sac, and sidewalks on 1 side of the street only) and residents in a new urbanist neighborhood (where there was both residential and nonresidential land use, modified grid street patterns, a mix of single-family and multi-family dwellings, and sidewalks on both sides of the streets). However, the number of weekly active transportation trips (cycling and walking) was higher among participants residing in the new urbanist neighborhood. Saelens et al.[8] found that U.S. adults residing in a high-walkable neighborhood (consisting of a variety of different destinations, including residences and businesses, and having mostly grid street patterns) undertook more weekly minutes of accelerometer-measured moderate-intensity PA compared with those residing in a low-walkable neighborhood (consisting mostly of residences with little commercial land use and having a mixture of grid and curvilinear street patterns and more cul-de-sac). Differences in the use of active transportation (local walking and cycling) explain some of the variation in the levels of MVPA found among residents in new urbanist neighborhoods *vs.* suburban neighborhoods.[7,9]

Controlling for residential or neighborhood selection—the choice to reside in a neighborhood with features that support behavioral preferences—is important because its omission from statistical models may bias the association between the built environment and PA.[10,11] In a study involving Canadian adults, neighborhood-based transportation walking, but not recreational walking, was higher in neighborhoods that included built characteristics consistent with traditional (more walkable) designs, after controlling for neighborhood selection.[12] In a US-based study, transportation walking was associated with walkable features of the neighborhood after controlling for neighborhood selection,[13] and, in a European-based study, it was found that perceived proximity to recreational facilities was associated with leisure PA after controlling for neighborhood selection.[14] Despite these findings, there have been only a few studies explicitly comparing different types of PA with different neighborhood designs while controlling for neighborhood selection. Notably, a review of quantitative evidence found, among 25 Canadian studies, only 3 estimated associations between the objectively measured built environment and walking after statistically controlling for neighborhood selection.[15] The lack of adjustment for neighborhood selection in observational studies of the association between the built environment and PA limits causal inference[16,17] and thus limits the quality of evidence that informs urban planning policy and practice.

To understand better the extent to which neighborhood design is associated with different types of PA, our study estimated levels of different transportation PA and leisure PA for 3 types of neighborhood design, with each defined by its street pattern (grid, warped-grid, or curvilinear) and adjusted for sociodemographic characteristics, reasons for neighborhood choice, and neighborhood socioeconomic status (SES). We hypothesized that volume (intensity × duration) of transportation PA and overall levels of PA (transportation and leisure combined) would be higher among participants residing in more walkable, grid and warped-grid neighborhoods than among those residing in less-walkable, curvilinear neighborhoods. We also hypothesized that participants residing in grid and warped-grid neighborhoods would be more likely to participate (any *vs*. none) in transportation walking and transportation cycling compared with those residing in curvilinear neighborhoods.

## 2. Methods

### 2.1. Study and sample design

The study design has been described elsewhere.[18−20] Briefly, in April 2014, a random stratified sample of adults (age ≥20 years; 1 adult per household) living in 12 established Calgary neighborhoods (Alberta, Canada) with different street patterns (grid, warped-grid, and curvilinear) and SES (quartiles) were invited by mail to complete 2 online, self-administered questionnaires that captured data on diet, PA, sociodemographic characteristics, and reasons for neighborhood choice (response rate = 10.1%; $n = 1023$, including 105 participants who requested and completed hardcopy versions). We estimated neighborhood SES by aggregating into a single index the following dissemination-area-level variables collected as part of the 2006 Canadian Census:[18−20] proportion of individuals 25−64 years of age who had not completed high school; proportion of single-parent families; proportion of rented private dwellings; proportion of divorced, separated, or widowed individuals among those ≥15 years of age; proportion of those ≥25 years of age who were unemployed; median gross household income; and average value of dwellings. To align with data collected using the Past Year Physical Activity Questionnaire (PYT-PAQ), only participants with complete data who reported residing in their neighborhood for at least 12 months were included in the analysis ($n = 854$). A questionnaire item captured the length of time participants had resided in their current neighborhood. The study was approved by the University of Calgary Conjoint Health Research Ethics Board. Each subject signed a written informed consent form to participate.

### 2.2. Measures

#### 2.2.1. PA

PYT-PAQ captured PA undertaken during the previous 12 months.[21] The PYT-PAQ captures frequency (count of months/year and days/week), and duration (minutes) of PA, including but not limited to PAs undertaken for transportation and leisure purposes. The PYT-PAQ has demonstrated reliability and validity for capturing PA in Canadian adults.[21] To aid recall, participants were prompted to consider the locations where their PA was undertaken (i.e., at home, inside the neighborhood, and outside the neighborhood). Reported leisure PAs and transportation PAs were assigned metabolic equivalents (METs; i.e., low-intensity: 1.5−2.4 METs; moderate-intensity: 2.5−5.9 METs; and vigorous-intensity: ≥6 METs) and MET-h/week were estimated.[22] Our PA outcomes excluded sedentary behavior.

### 2.2.2. Sociodemographic and health variables

The sociodemographic variables captured included age, gender, ethnicity (white or other), highest education attained (high school or less, technical college/trade school, or university), gross annual household income (<CAD60,000, CAD60,000−CAD119,999, ≥CAD120,000, or don't know/refused to answer), marital status (married/common law or other), number of children at home <18 years of age (≤1 or 0), dog ownership in past 12 months (owner or non-owner), motor vehicle access (always/sometimes or never/don't drive), and injury in the past 12 months that restricted normal PA (yes or no).

### 2.2.3. Reasons for neighborhood choice

Thirteen items, each with 3-point response options (i.e., 1 = not at all important, 2 = somewhat important, and 3 = very important), captured the participants' reasons for choosing to reside in their current neighborhood. Reasons included proximity to public transport, proximity to stores or services, proximity to recreational facilities, proximity to downtown, proximity to work, proximity to schools, access to highways or major roads, access to a community association, sense of community, attractiveness of streets, cleanliness of streets, variety of residential building types, and quality of recreation facilities, parks, and trails. These items have acceptable test−retest reliability.[23] For the current analyses, responses to these items were collapsed into 2 categories (not at all important *vs.* somewhat or very important).

### 2.2.4. Neighborhood design

In North America, relative to suburban neighborhoods (which typically have curvilinear street patterns with cul-de-sac), traditional neighborhoods (which typically have either grid or warped-grid street patterns) often offer built characteristics that provide better support for PA.[24,25] The 3 types of neighborhood designs compared in our study reflect eras of urban development in Calgary.[26,27] Pre-World War II traditional neighborhoods, named *grid*, typically offer high levels of pedestrian connectivity, permeability, and route choice; consist of a mix of land uses; and often include tree-lined boulevards with sidewalks on both sides of the street. The 4 grid neighborhoods included in our study were built between 1907 and 1948 and had an average Walk Score® (a composite measure of walkability) of 75.1 ± 5.7 (mean ± SD). Walk Score® (www.walkscore.com) is a publicly available objective indicator of walkability, with scores ranging from 0 (*least walkable*) to 100 (*most walkable*). According to the walkscore.com website, neighborhoods with scores >70 are very walkable, whereas neighborhoods with scores <50 are car-dependent. Post-World War II mixed neighborhoods, named *warped-grid*, typically have street patterns with crescents and curved roads, resulting in less pedestrian connectivity compared with the traditional grid neighborhoods. Warped-grid neighborhoods have fewer tree-lined boulevards, and sidewalks are directly adjacent to roads. They consist mostly of residential land, usually surrounding a centrally located elementary school and community center, with commercial developments at the edges. The 4 warped-grid neighborhoods in our study were built between 1953 and 1977 and had an average Walk Score® of 57.9 ± 8.8. Newer suburban neighborhoods, named *curvilinear*, typically have high-volume collector roads, a curvilinear "loops and lollipops" street pattern (often with a strip of auto-oriented commercial land, including shops and services), limited pedestrian connectivity, and sidewalks often missing from 1 or both sides of the street. The 4 curvilinear neighborhoods in our study were built between 1967 and 1982 and had an average Walk Score® of 46.0 ± 9.0 (Fig. 1).

### 2.2.5. Neighborhood SES

Adapted from previous Canadian research,[28] a neighborhood SES index was developed using the following Statistics Canada Census variables: proportion of those 25 to 64 years of age who had not completed high school; proportion of single-parent families; proportion of rented private dwellings; proportion of divorced, separated, or widowed among those ≥15 years of age; proportion of unemployed among those ≥25 years of age; median gross household income; and average value of dwellings. Values for each variable were converted to z-scores, summed to create an SES index, and then recoded into 2 groups based on the median (advantaged *vs.* disadvantaged neighborhoods).

## 2.3. Statistical analysis

We estimated descriptive statistics for all variables. Generalized linear models (binomial distribution with log link function) estimated the odds ratios (OR) and 95% confidence intervals (95%CIs) for associations between neighborhood design and participation in transportation and leisure PA outcomes, adjusting for neighborhood SES, sociodemographic characteristics (gender, age, ethnicity, education, household income, marital status, number of children, motor vehicle access, dog ownership, and injury), and reasons for neighborhood choice (e.g., proximity and quality of recreational and utilitarian destinations, proximity to work,

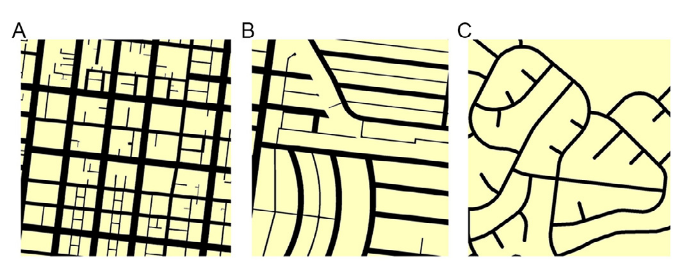


Fig. 1. Three types of neighborhood design in this study: (A) grid; (B) warped-grid; and (C) curvilinear.

access to highways, aesthetics, and sense of community). For participants reporting PA participation, we used generalized linear models (normal distribution with identity link function) to estimate marginal means for volume (MET-h/week) of transportation and leisure PAs by neighborhood design, adjusting for covariates. For our models, we estimated Huber-White robust standard errors. Analysis was undertaken using the Statistical Package for Social Sciences SPSS (Version 23.0; IBM Corp., Armonk, NY, USA).

## 3. Results

### 3.1. Sample characteristics

Participants from curvilinear neighborhoods were slightly older and less likely to have dependents <18 years living at home than participants from either warped-grid or grid neighborhoods (Table 1). Participants from curvilinear neighborhoods and warped-grid neighborhoods had lower levels of educational attainment compared with those from grid neighborhoods. The proportion of gross household incomes of at least CAD120,000/year was highest for grid neighborhood participants and lowest from curvilinear neighborhood participants. Relative to the other neighborhood designs, there was a significantly ($p < 0.05$) lower proportion of participants from advantaged warped-grid neighborhoods. Moreover, the proportion reporting an injury in the past year was lowest among warped-grid neighborhood participants and highest among grid neighborhood participants ($p < 0.05$). Participant gender, ethnicity, marital status, dog ownership, and motor vehicle access were not significantly different ($p > 0.05$) among the 3 neighborhood designs.

Relative to curvilinear and warped-grid neighborhood participants, a higher proportion of grid neighborhood participants reported proximity to stores, proximity to downtown, proximity to facilities, and proximity to work as important reasons for choosing their current neighborhood (Table 1). Relative to grid and curvilinear neighborhood participants, a higher proportion of warped-grid neighborhood participants reported access to a community association as an important reason for choosing their current neighborhood ($p < 0.05$). All other reasons for residential selection did not significantly differ ($p > 0.05$) among the 3 neighborhood designs.

Table 1
Sociodemographic characteristics and reasons for neighborhood selection by neighborhood design.

| Sociodemographic characteristic | | Curvilinear ($n = 290$) | Warped-grid ($n = 336$) | Grid ($n = 228$) |
|---|---|---|---|---|
| Age (year)[a] | | 57.5 ± 13.9*,# | 53.9 ± 13.7# | 50.7 ± 13.3 |
| Dependents <18 years (%) | Any | 22.8*,# | 34.5 | 36.8 |
| Gender (%) | Women | 57.9 | 65.2 | 60.1 |
| Ethnicity (%) | Nonwhite | 12.1 | 9.2 | 11.8 |
| Highest education achieved (%) | High school | 10.7# | 7.7 | 4.8 |
| | Technical college/trade school | 25.5# | 20.5# | 12.3 |
| | University | 63.8# | 71.7# | 82.9 |
| Gross household income (%) | <CAD60,000/year | 11.4 | 10.7 | 7.9 |
| | CAD60,000−CAD119,999/year | 35.2# | 29.2 | 24.1 |
| | ≥CAD120,000/year | 32.4*,# | 44.3 | 54.4 |
| | Don't know/refused | 21.0 | 15.8 | 13.6 |
| Marital status (%) | Married/common-law | 81.4 | 75.0 | 76.8 |
| Dog ownership in past year (%) | Owner | 29.7 | 32.4 | 30.7 |
| Motor vehicle access (%) | Never/don't drive | 19.0 | 12.8 | 14.9 |
| Injury in past year (%) | No injury | 60.3 | 58.3# | 67.5 |
| Current neighborhood socioeconomic status (%) | Disadvantaged | 25.9# | 44.3# | 28.9 |
| | Advantaged | 74.1# | 55.7# | 71.1 |
| Reasons for neighborhood choice | | | | |
| Proximity: transport (%) | Important | 56.9 | 58.6 | 63.2 |
| Proximity: stores/services (%) | Important | 76.6# | 76.5# | 87.3 |
| Proximity: recreational facilities (%) | Important | 80.3# | 81.3# | 89.0 |
| Proximity: downtown (%) | Important | 58.3*,# | 81.3# | 93.0 |
| Proximity to work (%) | Important | 66.6*,# | 79.5# | 87.3 |
| Proximity to schools (%) | Important | 66.6 | 69.0 | 64.5 |
| Access: highways/major roads (%) | Important | 76.9 | 77.1 | 70.2 |
| Access: community association (%) | Important | 38.3* | 48.8# | 36.8 |
| Sense of community (%) | Important | 71.7 | 75.0 | 76.3 |
| Attractiveness of streets (%) | Important | 82.1 | 80.4 | 85.5 |
| Cleanliness of streets (%) | Important | 84.1 | 78.9 | 78.9 |
| Variety of housing types (%) | Important | 66.6 | 64.0 | 64.9 |
| Quality of recreation facilities (%) | Important | 81.7 | 79.2 | 84.2 |

[a] Age is presented by mean ± SD. Pearson's $\chi^2$ with z-score pairwise *post hoc* comparisons used for estimated differences in categorical variables and one-way analysis of variance with Fisher's least significance difference pairwise *post hoc* comparisons used for estimated differences in continuous variables.
* $p < 0.05$, compared with Warped-grid; # $p < 0.05$, compared with Grid.

### 3.2. Neighborhood design, transportation walking, cycling, and PA

Compared with curvilinear neighborhood participants, grid neighborhood participants were twice as likely to report undertaking transportation walking (OR = 2.17, 95%CI: 1.42–3.31), transportation cycling (OR = 2.39, 95%CI: 1.35–4.23), and active transportation—undertaking any transportation walking or cycling—(OR = 2.16, 95%CI: 1.42–3.30), adjusting for all covariates (sociodemographic characteristics, neighborhood SES, and reasons for neighborhood selection). Furthermore, compared with curvilinear neighborhood participants, warped-grid participants were also more likely to report undertaking transportation cycling (OR = 2.74, 95%CI: 1.65–4.54) and active transportation (OR = 1.54, 95%CI: 1.06–2.22), adjusting for all covariates (Table 2). Volume of transportation PA (MET-h/week) did not significantly differ by neighborhood design (Table 3).

### 3.3. Neighborhood design, leisure walking, moderate-intensity, and vigorous-intensity PA

The likelihood of participating in leisure walking, low-intensity PA, or moderate-intensity PA did not differ by neighborhood design. After adjusting for all covariates, compared with curvilinear neighborhood participants, leisure cycling (OR = 1.70, 95%CI: 1.05–2.74) and vigorous-intensity leisure PA (OR = 1.74, 95%CI: 1.12–2.68) were more likely among grid

Table 2
Binary logistic regression ORs for the association between neighborhood street pattern and participation (any *vs.* none) in walking, cycling, low-intensity (<2.5 METs), moderate-intensity (2.5–5.9 METs), and vigorous-intensity (≥6.0 METs) physical activity.

| | Curvilinear ($n$ = 290) | | Warped-grid ($n$ = 336) | | Grid ($n$ = 228) | |
|---|---|---|---|---|---|---|
| Physical activity outcome | % participating | OR (95%CI) | % participating | OR (95%CI) | % participating | OR (95%CI) |
| Transportation walking[a] | 36.6 | 1 (ref.) | 45.8 | 1.20 (0.85–1.69) | 59.2 | 2.09 (1.42–3.05)* |
| Transportation walking[b] | | 1 (ref.) | | 1.20 (0.83–1.74) | | 2.17 (1.42–3.31)* |
| Leisure walking[a] | 62.1 | 1 (ref.) | 59.8 | 0.84 (0.59–1.38) | 59.6 | 0.95 (0.65–1.38) |
| Leisure walking[b] | | 1 (ref.) | | 0.86 (0.59–1.25) | | 0.97 (0.64–1.47) |
| Any purpose walking[a] | 73.4 | 1 (ref.) | 74.4 | 0.88 (0.60–1.29) | 79.4 | 1.23 (0.79–1.92) |
| Any purpose walking[b] | | 1 (ref.) | | 0.89 (0.59–1.36) | | 1.30 (0.80–2.12) |
| Transportation cycling[a] | 9.3 | 1 (ref.) | 23.5 | 2.98 (1.85–4.81)* | 25.9 | 2.59 (1.54–4.37)* |
| Transportation cycling[b] | | 1 (ref.) | | 2.74 (1.65–4.54)* | | 2.39 (1.35–4.23)* |
| Leisure cycling[a] | 21.7 | 1 (ref.) | 28.6 | 1.44 (0.97–2.12) | 36.0 | 1.68 (1.10–2.56)* |
| Leisure cycling[b] | | 1 (ref.) | | 1.40 (0.92–2.15) | | 1.70 (1.05–2.74)* |
| Any purpose cycling[a] | 24.8 | 1 (ref.) | 37.2 | 1.78 (1.23–2.58)* | 43.9 | 1.86 (1.24–2.80)* |
| Any purpose cycling[b] | | 1 (ref.) | | 1.69 (1.12–2.49)* | | 1.79 (1.14–2.82)* |
| Any active transportation[a] | 40.0 | 1 (ref.) | 55.4 | 1.55 (1.10–2.19)* | 66.2 | 2.26 (1.54–3.34)* |
| Any active transportation[b] | | 1 (ref.) | | 1.54 (1.06–2.22)* | | 2.16 (1.42–3.30)* |
| Any low-intensity leisure[a] | 24.1 | 1 (ref.) | 29.2 | 1.16 (0.79–1.71) | 35.1 | 1.43 (0.95– 2.16) |
| Any low-intensity leisure[b] | | 1 (ref.) | | 1.14 (0.75–1.72) | | 1.41 (0.89– 2.23) |
| Any moderate-intensity leisure[a] | 81.0 | 1 (ref.) | 80.4 | 0.82 (0.54–1.25) | 78.9 | 0.69 (0.43– 1.10) |
| Any moderate-intensity leisure[b] | | 1 (ref.) | | 0.87 (0.55–1.38) | | 0.75 (0.45– 1.26) |
| Any vigorous-intensity leisure[a] | 35.9 | 1 (ref.) | 50.3 | 1.62 (1.14–2.32)* | 58.8 | 1.85 (1.25– 2.72)* |
| Any vigorous-intensity leisure[b] | | 1 (ref.) | | 1.50 (1.02–2.22)* | | 1.74 (1.12– 2.68)* |

[a] Adjusted for all sociodemographic characteristics and neighborhood socioeconomic status.
[b] Adjusted for all sociodemographic characteristics, neighborhood socioeconomic status, and reasons for neighborhood selection. Active transportation includes transportation walking and cycling.
* $p < 0.05$.
Abbreviations: CI = confidence interval; MET = metabolic equivalent; OR = odds ratio; ref. = reference category.

Table 3
Leisure and transportation physical activity (MET-h/week) by neighborhood design for those reporting participation.

| | Curvilinear | | Warped-grid | | Grid | |
|---|---|---|---|---|---|---|
| Physical activity outcome | $n$ | Marginal mean (95%CI) | $n$ | Marginal mean (95%CI) | $n$ | Marginal mean (95%CI) |
| Leisure MET-h/week[a] | 275 | 33.39 (27.99–38.79) | 320 | 36.83 (30.54–43.12) | 220 | 37.74 (31.61–43.87) |
| Leisure MET-h/week[b] | | 34.30 (27.92–40.67) | | 37.18 (30.68–43.68) | | 37.29 (30.84–43.74) |
| Transportation MET-h/week[a] | 268 | 11.69 (9.80–13.59) | 323 | 11.84 (10.04–13.64) | 221 | 12.38 (10.16–14.61) |
| Transportation MET-h/week[b] | | 12.45 (10.37–14.53) | | 12.63 (10.56–14.70) | | 13.58 (10.89–16.26) |
| Total MET-h/week[a] | 286 | 42.36 (36.36–48.36) | 329 | 45.98 (39.07–52.90) | 228 | 46.66 (39.92–53.40) |
| Total MET-h/week[b] | | 42.93 (35.95–49.92) | | 46.35 (39.07–53.63) | | 46.42 (39.10–53.75) |

[a] Adjusted for all sociodemographic characteristics and neighborhood socioeconomic status.
[b] Adjusted for all sociodemographic characteristics, neighborhood socioeconomic status, and reasons for neighborhood selection.
Abbreviations: CI = confidence interval; MET = metabolic equivalent.

neighborhood participants. Vigorous-intensity leisure PA was also more likely among warped-grid participants compared with curvilinear participants (OR = 1.50, 95%CI: 1.02−2.22) (Table 2). Volume of total leisure PA (MET-h/week) did not significantly differ by neighborhood design (Table 3).

### *3.4. Neighborhood design and transportation and leisure PA combined*

Adjusting for all covariates, compared with curvilinear neighborhood participants, participants from warped-grid and grid neighborhoods were more likely to report cycling for transportation and leisure combined (OR = 1.69, 95%CI: 1.12−2.49, and OR = 1.79, 95%CI: 1.14−2.82, respectively). No significant neighborhood differences were found for walking for any purpose (transportation and leisure combined) (Table 2). Furthermore, weekly total MET-h for transportation and leisure PA combined did not differ by neighborhood design (Table 3).

## 4. Discussion

We compared transportation and leisure PA among 3 neighborhood types (grid, warped-grid, and curvilinear), adjusting for sociodemographic characteristics, reasons for neighborhood choice, and neighborhood SES. Consistent with previous studies,[29,30] we found the associations of built environment with PA differ depending on the type of PA examined. Our hypothesis that participants residing in grid and warped-grid neighborhoods would be more likely to participate in transportation walking and cycling compared with those residing in curvilinear neighborhoods was supported. Notably, adjustment for neighborhood selection (reasons for neighborhood choice) had no impact on the interpretation of the findings of our study, despite attenuating some estimates (participation in transportation cycling, cycling for any purpose, active transportation, and vigorous-intensity PA).

Compared with curvilinear neighborhoods, grid and warped-grid neighborhoods were found to be positively associated with participation in transportation walking and cycling, leisure cycling, active transportation, and vigorous-intensity PA. This is consistent with some previous findings suggesting that neighborhoods with a grid street pattern are associated with PA in adults.[24,25,31,32] For instance, a recent study conducted in Japan found that those adults who lived in neighborhoods with well-connected streets (i.e., grid pattern layouts) reported more walking and less driving compared with those in areas with less-connected streets.[32] There may be several reasons why grid-like street patterns are associated with active behaviors. Compared with curvilinear street layouts, grid street patterns can provide more direct and short routes between origins and destinations.[33] More connected streets are also likely to attract more commercial destinations to which individuals can walk.[34] For instance, a study conducted in Australia found that the associations of well-connected streets with adults' transportation walking were partially mediated by local commercial destinations.[34] Importantly, our findings suggest that neighborhood street patterns may shape PA patterns in adults, even after reasons for neighborhood choice are taken into account. However, we acknowledge that in all cases except transportation walking, where we observed a statistically significant association, further adjustment for neighborhood selection only slightly attenuated the estimate. This is reassuring given that most cross-sectional studies estimating relationships between the built environment and PA to date have not accounted for neighborhood selection. It is likely that, in many of these studies, the adjustment for neighborhood selection might have had only a small effect on the estimates and would likely not have changed their conclusions. The independent association between the built environment and PA found in our study is consistent with findings elsewhere,[16] including previous Canadian studies that have statistically controlled for neighborhood selection.[15] These more rigorous cross-sectional findings contribute to the accumulating evidence from natural experiments and residential relocation studies[35−37] that suggest a causal relation between the neighborhood-built environment and PA is highly probable.

Our study findings, however, suggest that, although neighborhood street design likely influences participation in PA, it may not result in higher volumes of or energy expended on PA being undertaken for transportation and leisure. Moreover, the prevalence of leisure walking, moderate-intensity PA, and low-intensity PA also did not significantly differ by neighborhood street design. Other studies have found more leisure walking among those residing in neighborhoods with less-connected streets,[38,39] yet this was not the case in our study. For example, a U.S. study found that the odds of undertaking leisure walking were higher in areas with less-connected streets.[38] Another study in Belgium also found a negative association between perceived street connectivity and adults' leisure walking.[39] Traffic safety may be better in areas with less-connected streets than in areas with high-connected streets, which could encourage more leisure walking.[40] For instance, a study conducted in Calgary, Canada, found that the probability of crash injuries is higher in areas with a less-connected street pattern, although such a layout reduces the probability of crash fatalities.[40]

Nonenvironmental, neighborhood-targeted health promotion interventions[41] might be needed in situations where a built-environment modification or the built design of an existing neighborhood is positively associated with 1 type of PA while also being negatively associated with another type of PA. Our finding that neighborhood design might be more strongly associated with "participation" (or initiation) in PA than with volume of PA suggests that non-environment-related health promotion strategies,[41] such as informational interventions (e.g., community campaigns, point of decision prompts) and behavioral and social interventions (e.g., individually adapted behavior change, social support groups and networks), might be needed to encourage those who do participate to increase the amount or volume of PA they undertake. More research is needed on the potential of environmental and health promotion strategies and their interactions for increasing the amount of PA among those residents who are already active or who are in the process of initiating PA.

We acknowledge several limitations of our study. Despite statistically adjusting for neighborhood selection in addition to other potential confounders, our cross-sectional data do not allow us to draw temporal causal inferences about the relationship between neighborhood design and PA. Longitudinal studies and natural experiments are needed to inform temporal causal inferences.[42,43] Self-reports of PA are prone to measurement errors and may result in fewer true differences being detected in the relationship between PA and neighborhood design. We captured the participants' level of PA undertaken in the past year, thus taking into account seasonal PA patterns; however, our estimates do not differentiate between PA undertaken inside and outside the neighborhood. We did not include perceived measures of the built environment. Perceived and objective measures of the built environment typically have low agreement,[44,45] but both may independently contribute to PA.[12] Given our main interest in estimating the magnitude and direction of associations between neighborhood design and PA, our sample included households from neighborhoods across the socioeconomic and urban form spectrum. Nevertheless, the low but conservative response rate may limit the generalizability of our study and may reflect a more motivated and active sample. Furthermore, despite randomly selecting neighborhoods, our study included only 12 neighborhoods, and these neighborhoods may not have fully captured the differences in urban design found throughout Calgary. Finally, residential self-selection items captured responses on a 3-point scale, which might have resulted in participants being more likely to report their reasons for moving to their current neighborhood as important. Despite these limitations, our findings are similar to those of previous studies that included a random cross-section of Calgary households.[46]

## 5. Conclusion

This study provided evidence showing the importance of neighborhood design in relation to different types of adults' active behaviors: compared with curvilinear neighborhoods, grid and warped-grid neighborhoods had higher participation in most PAs examined. Notably, this relationship existed even with statistical adjustment for neighborhood selection, household- and neighborhood-level SES, and other sociodemographic characteristics. More evidence on the role of neighborhood design in enabling or restricting different types of PA is necessary to inform local urban design and public health interventions that might result in net gains in population levels of PA. Municipal land use and urban design policies and incentives that deter the development of curvilinear or "suburban" (i.e., low walkable) neighborhoods and encourage the development of grid or warped-grid (i.e., high walkable) neighborhoods are needed to improve PA in the population. Neighborhood design may be more strongly related to participation in PA (i.e., any *vs.* none) rather than the volume of PA undertaken among participators.

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## Authors' contributions

GRM conceived and designed the study, analyzed data, interpreted the findings and contributed to writing the manuscript; AB and BF analyzed data, interpreted the findings, and contributed to writing the manuscript; MJK, KO, CMF, and FUA interpreted the findings and contributed to writing the manuscript. All authors have read and approved the final version of the manuscript, and agree with the order of the presentation of authors.

## Competing interests

The authors declare that they have no competing interests.

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