Cross-sectional associations between neighbourhood walkability and objective physical activity levels in identical twins

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ABSTRACT

Objectives Physical activity is a cornerstone of chronic disease prevention and treatment, yet most US adults do not perform levels recommended for health. The neighborhood–built environment (BE) may support or hinder physical activity levels. This study investigated whether identical twins who reside in more walkable BEs have greater activity levels than twins who reside in less walkable BEs (between-twin analysis), and whether associations remain significant when controlling for genetic and shared environmental factors (within-twin analysis).

Design A cross-sectional study.

Setting The Puget Sound region around Seattle, Washington, USA.

Participants The sample consisted of 112 identical twin pairs who completed an in-person assessment and 2-week at-home measurement protocol using a global positioning system (GPS) monitor and accelerometer.

Exposure The walkability of each participants’ place of residence was calculated using three BE dimensions (intersection density, population density and destination accessibility). For each variable, z scores were calculated and summed to produce the final walkability score.

Outcomes Objectively measured bouts of walking and moderate-to-vigorous physical activity (MVPA), expressed as minutes per week.

Results Walkability was associated with walking bouts (but not MVPA) within the neighbourhood, both between (b=0.58, SE=0.13, p<0.001) and within pairs (b=0.61, SE=0.18, p<0.001). For a pair with a 2-unit difference in walkability, the twin in a more walkable neighbourhood is likely to walk approximately 16 min per week more than the co-twin who lives in a less walkable neighbourhood.

Conclusions This study provides robust evidence of an association between walkability and objective walking bouts. Improvements to the neighbourhood BE could potentially lead to increased activity levels in communities throughout the USA.

INTRODUCTION

Regular physical activity is a cornerstone of chronic disease prevention and treatment. The Physical Activity Guidelines for Americans provides evidence-based guidance to help individuals to maintain or improve their health through physical activity. Unfortunately, most Americans do not perform physical activity at levels recommended for health. Strategies to increase levels of physical activity in the US population are a critical public health goal.

The role of the built environment (BE) in supporting or hindering physical activity levels in the population has garnered substantial attention over the last several decades. BE correlates of walking, such as the presence of sidewalks, density of road network connections and having utilitarian destinations within a short distance from the home, are well documented.

Most research-linking features of the BE with physical activity is limited because it is often unclear whether the activity occurred inside the neighbourhood of residence or in other distal locations. In addition, the definition of what constitutes a ‘neighbourhood’ is debatable. We recently described methods to precisely allocate objective measures of

STRENGTHS AND LIMITATIONS OF THIS STUDY

- We used a sample of twins and robust methods to control for familial confounds and included other important sociodemographic factors in statistical models.
- Physical activity was measured objectively in time and space, providing rich information on bouts of activity where they occurred (ie, inside or outside of the home neighbourhood).
- The sample of twins was mostly urban, white and non-Hispanic, with education and income levels higher than the US population average; findings should be replicated in samples drawn from diverse sociodemographic groups and locations (ie, rural residents) to increase generalisability.
- The cross-sectional study design precludes casual inferences.
physical activity spatially and temporally \(^1^4\) to investigate associations with exposure to home and non-home neighbourhood environments, methods we employed in the present study. Another limitation is the inability to draw causal inferences in observational research. To address this limitation, we use identical twins (monozygotic (MZ)) reared together; these matched pairs serve as quasiexperimental controls because MZ twins share genetic and early-life environmental factors that cannot be held constant in the absence of random assignment and would otherwise confound statistical associations.\(^1^5\)

We build on previous concepts and extend the literature by investigating associations between walkability of the home BE and levels of objectively measured walking and moderate-to-vigorous physical activity (MVPA) performed within and outside of the residential neighbourhood in a sample of MZ twins reared together as children but residing apart as adults. We hypothesised that twins who reside in more walkable BEs have greater walking and MVPA levels than twins who reside in less walkable BEs (between-twin analysis). We further hypothesised that these findings would remain significant when controlling for genetic and shared environmental factors (within-twin analysis).

**METHODS**

**Study design and setting**

This was a cross-sectional study of objective measures of physical activity amounts and locations among individuals living in the Puget Sound region around Seattle, Washington, USA. Participants wore a Qstarz BT-Q1000XT GPS data logger (Qstarz International Co, Taipei, Taiwan) and Actigraph GT3X+ accelerometer (Actigraph, Pensacola, Florida, USA) attached to an elastic belt worn around the waist to collect data under free-living conditions over a 2-week period. Data were collected during 2012–2019.

**Participants**

This study recruited MZ twin pairs from the community-based Washington State Twin Registry (WSTR). Procedures and details of the WSTR are reported elsewhere.\(^1^6\)\(^1^7\) Recruited twins completed an in-person study visit followed by a 2-week remote data collection protocol. Inclusion criteria were living at the primary residence for at least 1 year and absence of physical conditions that limited mobility. The final sample consisted of 375 twins (the ‘full’ sample), from which 224 twins (n=112 complete pairs, the ‘analytic’ sample) had complete data and met the minimum criteria for valid monitor days, defined as a minimum of 10 hours of accelerometer ‘wearing’\(^1^8\) and any GPS data per day over 10 (out of 14) days. On average, the devices were worn for 12.7±1.3 days.

**Patient and public involvement**

Patients and the public were not involved in the design, conduct, analysis or interpretation of the study. Study participants could have access to the study results on request.

**Outcome measures**

Objective physical activity levels were operationalised as walking bout minutes per week and MVPA bout minutes per week. Walking bouts were identified using a classification algorithm adapted from Kang et al.\(^1^9\) described by us previously\(2^0\) and in brief below. MVPA bouts were identified as sustained intervals with 3D vector magnitude≥2690 counts per minute (CPM)\(^2^1\) using a modified 10 min bout definition that allows for up to 2 min outside the specified CPM threshold.\(^1^8\) Accelerometry and GPS data were combined into ‘LifeLogs’ using common timestamps.\(^2^2\) Light-to-moderate physical activity (LMPA) bouts used vector magnitude thresholds between 2000 and 6166 CPM. Walking bouts were identified as the subset of LMPA bouts that had (1) at least three records with GPS coordinates, (2) ≥20% of records with GPS coordinates, (3) median Doppler shift-based GPS speed between 2 and 6 km/hour and (4) spatial configuration. The spatial configuration criterion calculates the interpoint distance for all GPS coordinates in the bout and creates a minimum bounding circle (MBC) around the 95% most tightly clustered points in the bout; bouts with MBC>20 m that met all other criteria were flagged as walking.

As described previously,\(^1^4\) two geometric buffer types (Euclidean and ‘sausage’) of different radii (833 and 1666 m) to represent the distance typically walked in 10 and 20 min, respectively.\(^1^2\)\(^2^3–2^5\) location (inside or outside of the defined neighbourhood) and containment of activity bouts (strict—ie, completely inside or outside and flexible—ie, with partial containment) were constructed. Estimates were generated for both MVPA and walking bouts and were normalised per participant as minutes per week. Device data management and buffer construction used PostgreSQL V.10.12, an open-source SQL database with PostGIS V.3.0\(^2^6\) to support geographic information system data and a large set of standard functions for spatial analysis.

**Exposure measures**

The walkability of each study participants’ place of residence was determined with methods derived from the Built Environment and Health Research Group Neighborhood Walkability Index (BEH-NWI).\(^2^7\) The Walkability Index has three dimensions to measure urban BE features promoting higher likelihood of walking as a mode of transport: (1) intersection density, (2) population density and (3) destination accessibility. Spatial analyses were performed using PostGIS.

For intersection density, TIGER/Line shapefiles for each study year’s roads were used to analyse the number of intersections within a 1 km Euclidean buffer of the participant’s residential address. The American Community Survey was used to estimate population at the census tract level for each study year. Study participants’ population density was calculated using area-weighted population...
counts from the census tracts overlapping the Euclidean buffer. For destination accessibility, InfoUSA (now Data Axle) data for each study year were used to map business destinations considered to be ‘walk promoting’ (ie, utilitarian destinations that people often walk to). InfoUSA datasets included XY coordinates and business type, coded using 6-digit Standard Industrial Classification (SIC) Codes. SIC codes for ‘walk-promoting’ businesses were based on similar descriptions from the previous BEH-NWI classification of the National Establishment Times Series data. Study participants’ destination accessibility was considered as the number of ‘walk-promoting’ businesses within a 1 km Euclidean buffer of the participant’s residential address.

For each variable (intersection density, population density and destination accessibility), z scores for each study participant were calculated based on the entire sample. These z scores were summed to calculate final Walkability Index scores.

Age, sex, education and income were used as covariates in the statistical analyses. Age was computed based on the reported date of birth. Sex was self-reported as male or female. Education referred to the highest level of education completed, ranging from ‘less than high school’ to ‘master’s degree or higher’. Income refers to the total household income from all sources ranging from ‘less than US$20 000’ to ‘US$150 000 or more’.

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**Table 1** Descriptive statistics of select sample characteristics

<table>
<thead>
<tr>
<th></th>
<th>Full sample (N=375)</th>
<th>Excluded sample (N=151)</th>
<th>Analytic sample (N=224)</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sex (male)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>N</td>
<td>105</td>
<td>39</td>
<td>66</td>
<td>0.514</td>
</tr>
<tr>
<td>%</td>
<td>28.0</td>
<td>25.8</td>
<td>29.5</td>
<td></td>
</tr>
<tr>
<td>Education level*</td>
<td></td>
<td></td>
<td></td>
<td>0.325</td>
</tr>
<tr>
<td>Less than high school</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>%</td>
<td>0.81</td>
<td>1.3</td>
<td>0.5</td>
<td></td>
</tr>
<tr>
<td>High school graduate</td>
<td>28</td>
<td>12</td>
<td>16</td>
<td></td>
</tr>
<tr>
<td>%</td>
<td>7.5</td>
<td>8.1</td>
<td>7.2</td>
<td></td>
</tr>
<tr>
<td>Some college</td>
<td>90</td>
<td>43</td>
<td>47</td>
<td></td>
</tr>
<tr>
<td>%</td>
<td>24.2</td>
<td>28.9</td>
<td>21.1</td>
<td></td>
</tr>
<tr>
<td>Bachelor’s degree</td>
<td>136</td>
<td>51</td>
<td>85</td>
<td></td>
</tr>
<tr>
<td>%</td>
<td>36.6</td>
<td>34.2</td>
<td>38.1</td>
<td></td>
</tr>
<tr>
<td>Master’s degree or higher</td>
<td>115</td>
<td>41</td>
<td>74</td>
<td></td>
</tr>
<tr>
<td>%</td>
<td>30.9</td>
<td>27.5</td>
<td>33.2</td>
<td></td>
</tr>
</tbody>
</table>

Household income†

|                       |                     |                          |                          | 0.006   |
| <US$20,000            | 10                  | 4                        | 6                        |         |
| %                       | 2.8                | 2.8                      | 2.7                      |         |
| US$20,000–US$29,999   | 7                   | 5                        | 2                        |         |
| %                       | 1.9                | 3.5                      | 0.9                      |         |
| US$30,000–US$39,999   | 27                  | 9                        | 18                       |         |
| %                       | 7.4                | 6.3                      | 8.2                      |         |
| US$40,000–US$49,999   | 24                  | 14                       | 10                       |         |
| %                       | 6.6                | 9.8                      | 4.5                      |         |
| US$50,000–US$59,999   | 35                  | 15                       | 20                       |         |
| %                       | 9.6                | 10.5                     | 9.1                      |         |
| US$60,000–US$69,999   | 24                  | 10                       | 14                       |         |
| %                       | 6.6                | 7.0                      | 6.4                      |         |
| US$70,000–US$79,999   | 35                  | 15                       | 20                       |         |
| %                       | 9.6                | 10.5                     | 9.1                      |         |
| US$80,000–US$89,999   | 142                 | 38                       | 104                      |         |
| %                       | 39.1               | 26.6                     | 47.3                     |         |
| US$90,000–US$99,999   | 5                   | 3                        | 2                        |         |
| %                       | 1.4                | 2.1                      | 9.1                      |         |
| US$100,000–US$149,999 | 20                  | 10                       | 10                       |         |
| %                       | 5.5                | 7.0                      | 4.5                      |         |
| US$150,000+           | 34                  | 20                       | 14                       |         |
| %                       | 9.4                | 14.0                     | 6.4                      |         |

M, mean; MVP, moderate-to-vigorous physical activity.

Proportions are computed based on sample with non-missing data. Chi-square/Fisher’s exact tests (for categorical variables) and linear regression models (for continuous variables) are used to compare the descriptive statistics between the excluded sample and the analytic sample. Variables with significant differences between the excluded and analytic samples indicated in the p value column (p<0.05).

*Education level missing for two individuals in the excluded example and one in the analytic sample. Proportions are computed based on sample with non-missing data.

†Household income missing for eight individuals in the excluded sample and four in the analytic sample.
Statistical analysis

Descriptive statistics are presented as counts and proportions (for categorical variables) and means and standard deviations (for continuous variables). Chi-square/Fisher’s exact tests (for categorical variables) and linear regression models (for continuous variables) were used to compare the descriptive statistics between the excluded sample and the analytic sample.

A series of linear mixed effects models (LMMs) were used to examine the associations between walkability and physical activity levels. The LMM takes the form of:

\[ Y_{ij} = \beta_0 + \beta_1 X_{ij} + u_{0j} + \epsilon_{ij} \]

where \( Y_{ij} \) represents the physical activity of the \( i \)th twin within the \( j \)th pair, \( \beta_0 \) is the population intercept, \( \beta_1 \) refers to expected change in physical activity given an increase in 1-unit walkability; these are the fixed effects portion of the model. The random effects portion of the model consists of \( u_{0j} \), the pair-level error and \( \epsilon_{ij} \), the individual-level error of prediction. This model takes into account correlations between members of a pair (\( u_{0j} \)), but not controlling for pair-level confounds. The regression coefficient, \( \beta_1 \), in this model reflects the ‘phenotypic association’ between walkability and physical activity (model 1). Next, we included the mean walkability between twin pairs (\( X_{ij} \)) into the LMM (model 2):

\[ Y_{ij} = \beta_0 + \beta_1 X_{ij} + \beta_2 X_{ij} + u_{0j} + \epsilon_{ij} \]

In addition to controlling for the correlations between members of a pair (\( u_{0j} \)), this model further controls for the between-family genetic and environmental differences that are confounded with average walkability. The regression coefficient, \( \beta_2 \), in this model (individual level) represents the ‘quasicausal’ effect of walkability on physical activity, controlling for between-pair confounds. The regression coefficient for the pair mean (\( \beta_{02} \)) is an estimate of the magnitude of the between-pair confound. The term ‘quasicausal’ refers to phenotypic associations that have survived analysis using quasi-experimental methods (ie, within-twin). In the final set of models further investigated the potential effect of between-pair confounds by including participants’ age, sex, educational attainment and annual household income (model 3).

Because walking bouts and MVPA bouts were highly skewed, all physical activity variables were square root transformed. With 17 tests performed for each physical activity outcome in each model, a Bonferroni corrected alpha was used to set the statistical significance level at \( \alpha = 0.05/17 = 0.003 \). All statistical analyses were performed in the statistical programme R V.4.0.2.

RESULTS

Sociodemographic characteristics of the full (n=375), excluded (n=151) and analytic samples (n=224) are presented in table 1. There were no differences between the excluded and analytic samples with respect to sex, education level, age and objective physical activity levels.

However, the distribution of income-level categories and neighbourhood walkability were both significantly different between the analytic and excluded samples.

Descriptive statistics of objective physical activity levels by buffer type, size, location and containment are shown in online supplemental table 1. Between-pair and within-pair correlations between walkability and physical activity levels are shown in online supplemental table 2.

### Association between walkability and walking

In the next sections, results and tables focus on overall objective activity levels, with and without controlling for pair-level confounds and sociodemographic variables, for simplicity. We then highlight results for activity levels inside and outside the neighbourhood, by buffer type, size and containment definition, with full results included in the supplemental tables.

There was a positive association between walkability and walking bouts (model 1 in table 2, \( b=0.58, SE=0.13, p<0.001 \)). A 1-unit increase in walkability was associated with a 0.58-unit increase in \( \sqrt{\text{walking (min/week)}} \). As illustrated in figure 1 (left panel), a 1-unit increase in walkability was associated with an average 0.34 min (0.58\(^2\)) increase in walking per week, whereas a 10-unit increase in walkability was associated with an \( \sim 34 \text{min} \) increase in walking per week. However, the large standard errors at the higher ends of the walkability index reflected a large variation in the increase in walking minutes per week (~19 to 50 min per week increase for a 10-unit increase in walkability) when the increase in walkability was large, suggesting the results are not estimated with precision.

The estimate in model 1 represents the ‘phenotypic’, or uncontrolled, association between walkability and walking. Model 2 controls for pair-level confounds, Table 2 Overall associations between walking and walkability among identical twins

<table>
<thead>
<tr>
<th>Model</th>
<th>Estimate</th>
<th>SE</th>
<th>95% CI</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.58</td>
<td>0.13</td>
<td>0.31 to 0.84</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>2</td>
<td>Individual 0.61</td>
<td>0.18</td>
<td>0.24 to 0.97</td>
<td>0.001</td>
</tr>
<tr>
<td>Mean</td>
<td>−0.06</td>
<td>0.27</td>
<td>−0.59 to 0.46</td>
<td>0.816</td>
</tr>
<tr>
<td>3</td>
<td>Individual 0.58</td>
<td>0.18</td>
<td>0.21 to 0.94</td>
<td>0.002</td>
</tr>
<tr>
<td>Mean</td>
<td>−0.03</td>
<td>0.27</td>
<td>−0.56 to 0.50</td>
<td>0.920</td>
</tr>
</tbody>
</table>

The estimate in model 1 represents the ‘phenotypic’, or uncontrolled, association between walkability and walking. Model 2 controls for pair-level confounds, where the individual regression coefficient represents the ‘quasi-causal’ association between walkability and walking, and the mean regression coefficient is an estimate of the magnitude of the pair-level confound. Model 3 further controls for age, sex, education, and income.

Statistical significance established at \( p < 0.003 \) based on the Bonferroni corrected alpha. Walking is square root transformed.

95%CI, 95% confidence interval; SE, standard error.
where the individual regression coefficient represents the 'quasicausal' association between walkability and walking, and the mean regression coefficient is an estimate of the magnitude of the pair-level confound. Model 3 further controls for age, sex, education and income.

Statistical significance established at \( p<0.003 \) based on the Bonferroni corrected alpha.

Walking is square root transformed.

There was a quasicausal association between walkability and walking (model 2 in table 2, \( b=0.61, SE=0.18, p=0.001 \)), suggesting that within a pair of MZ twins, the twin who lives in a more walkable neighbourhood is more likely to walk more than the co-twin who lives in a less walkable neighbourhood. As illustrated in figure 2 (left panel), the within-pair difference in walking increases with increased within-pair difference in walkability. Results indicate that for an MZ twin pair with a 2-unit difference in walkability, the twin who lives in a more walkable neighbourhood is likely to walk approximately 16 ±5 min per week more than their co-twin who lives in a less walkable neighbourhood. However, the estimation error increases as the within-pair difference in walkability increases, because few twins live in neighbourhoods with large differences in walkability compared with their co-twins. Results were consistent after further adjusting for sociodemographic variables (model 3 in table 2, \( b=0.58, SE=0.18, p=0.002 \)).

Positive associations were observed between walkability and walking for several Euclidean buffer, size, location and containment definition combinations (online supplemental table 3). For example, walking bouts inside the 833 m (flexible containment \( b=0.52, SE=0.10, p<0.001 \) and strict containment \( b=0.43, SE=0.08, p<0.001 \)) and 1666 m buffers (flexible containment \( b=0.63, SE=0.12, p<0.001 \) and strict containment \( b=0.53, SE=0.11, p<0.001 \)) were significantly associated with walkability.

A 1-unit increase in walkability was associated with a 0.43–0.63-unit increase in \( \sqrt{\text{walking (min/week)}} \), reflecting that a 1-unit increase in walkability was associated with an average of 0.18 min \((0.43^2)\) to 0.40 min \((0.63^2)\) increase in walking per week. A 10-unit increase in walkability was associated with an approximate 18 min \((0.43 \times 10)^2\) to 40 min \((0.63 \times 10)^2\) increase in walking per week.

Similar patterns of positive associations between walkability and walking were found for several of the sausage buffer, size, location and containment definition combinations (online supplemental table 3). Results indicate that a 1-unit increase in walkability was associated with

**Figure 1**
Expected increase in overall objective walking (left panel) and moderate-to-vigorous physical activity (MVPA) (right panel) per unit increase in walkability. Shaded area denotes SE.

**Figure 2**
Within-pair difference in walkability and within-pair difference in overall objective physical activity among identical twins. Within-pair difference in walkability and within-pair difference in walking (left panel). Within-pair difference in walkability and within-pair difference in moderate-to-vigorous physical activity (MVPA) (right panel). Shaded area denotes SE.
a less than 1-unit increase in \( \sqrt{\text{walking (min/week)}} \) for most of the sausage buffer combinations. For example, a 1-unit increase in walkability was associated with minimal increases in walking minutes per week (0.04 min=0.21 for 833 m/inside/strict to 0.38 min=0.62 for 1666 m/inside/flexible). A 10-unit increase in walkability was associated with an approximate 4 min \((0.21 \times 10)^2\) for 833 m/inside/strict to 38 min \((0.62 \times 10)^2\) for 1666 m/inside/flexible) increase in walking per week.

Similarly, quasi-causal associations (noted with \( p \text{ values}<0.003 \)) were observed for several of the Euclidean and sausage buffer, size, location and containment combinations (online supplemental table 4). Results were mostly consistent after adjusting for additional confounding sociodemographic variables (online supplemental table 5).

**Association between walkability and MVPA**

There was a positive association between walkability and MVPA bouts (model 1 in **table 3**, \( b=0.50, \text{SE}=0.15, \text{p}<0.001 \)), suggesting that MVPA levels increase with increased neighbourhood walkability. As shown in **figure 1** (right panel), a 1-unit increase in walkability was associated with an average 0.25 min \((0.5^2)\) increase in MVPA per week, whereas a 10-unit increase in walkability was associated with an \(-25\text{ min} \((0.5 \times 10)^2\) increase in MVPA per week. However, the large standard errors at the higher ends of the walkability scale reflect a large variation in the increase in MVPA minutes per week \((-12\text{ to }42\text{ min increase at a 10-unit walkability increase})\), suggesting that the results are not estimated with precision. However, the quasi-causal association between walkability and MVPA bouts was not significant (model 2 in **table 3**, \( b=0.40, \text{SE}=0.20, \text{p}=0.049 \)). Thus, the amount of MVPA was similar for a pair of MZ twins who live in neighbourhoods of different walkability (**figure 2**, right panel).

The estimate in model 1 represents the ‘phenotypic’, or uncontrolled, association between walkability and MVPA. Model 2 controls for pair-level confounds, where the individual regression coefficient represents the ‘quasicausal’ association between walkability and MVPA, and the mean regression coefficient is an estimate of the magnitude of the pair-level confound. Model 3 further controls for age, sex, education and income.

Statistical significance established at \( p<0.003 \) based on the Bonferroni corrected alpha.

MVPA is square root transformed.

We observed positive associations between walkability and MVPA bouts for several Euclidean buffer size, location and containment combinations, including the 1666 m/inside/flexible \((b=0.53, \text{SE}=0.15, \text{p}<0.001 \)) and 1666 m/inside/strict \((b=0.44, \text{SE}=0.14, \text{p}=0.002 \)) combinations, and for the sausage buffer for the 833 m/inside/flexible \((b=0.41, \text{SE}=0.11, \text{p}<0.001 \)) and 1666 m/inside/flexible \((b=0.52, \text{SE}=0.13, \text{p}<0.001 \)) combinations (online supplemental table 6). A 1-unit increase in walkability was associated with less than a 1 min increase in MVPA per week, while a 10-unit increase in walkability was associated with a maximum average of a 28 min \((0.53 \times 10)^2\) for Euclidean buffer 1666 m/inside/flexible) increase in MVPA per week. However, none of the quasi-causal associations were significant. Full results for walkability and MVPA by buffer type, size, location and containment are shown in online supplemental table 7 (controlling for pair-level confounds) and online supplemental table 8 (further controlling for sociodemographic variables).

**DISCUSSION**

The major new finding from this study is that objectively measured neighbourhood walkability was associated with objectively measured walking bouts, both between and within twin pairs. This provides robust evidence of a ‘quasicausal’ association between an important environmental exposure—home neighbourhood walkability—and physical activity behaviour, specifically walking.

We found that overall, a 10-unit increase in walkability was associated with a 34 min per week increase in walking. This change is equivalent to an ~50% improvement in neighbourhood walkability based on the range of values for the exposure in this study \((-3.6\text{ to }16\)) . To put these findings in perspective, we calculated what a 10-unit change in our walkability index represents in terms of an actual BE. We then matched these environments to the Walk Score descriptive categories (with values ranging between 0 and 100) and found that a 10-unit difference represents the difference between a car-dependent (0–24, almost all errands require a car) and the upper value of a somewhat walkable neighbourhood (50–69, some errands can be accomplished on foot).\(^{28–32}\) This finding is clinically important and is consistent with the concept of...
performing 30 min of moderate intensity physical activity on most days of the week.\textsuperscript{1} \textsuperscript{2} \textsuperscript{3} Even small increases in physical activity at the population level can contribute to widespread improvements in public health.\textsuperscript{34} \textsuperscript{35} Thus, findings from this study can inform policies and regulations, such as funding for urban design and infrastructure that improve neighbourhood walkability and support active modes of transportation, namely walking.

Importantly, the findings remained consistent when submitted to genetically informed twin models that control for familial confounds. For a pair of MZ twins with a 2-unit difference in walkability, the twin who lives in a more walkable neighbourhood is likely to walk approximately 16 min per week more than their co-twin who lives in a less walkable neighbourhood. Our findings support and extend a large body of literature describing associations between neighbourhood walkability and walking levels among unrelated individuals\textsuperscript{36}–\textsuperscript{38} by controlling for statistical confounds that would otherwise be uncontrolled or not measured (ie, structural confounding).\textsuperscript{39} Our findings are also consistent with an earlier study from our group demonstrating that walkability and self-reported neighbourhood walking levels were ‘quasicausally’ related.\textsuperscript{40} Here, we replicate those earlier findings with objective data measured within a spatiotemporal framework, providing robust evidence to support the relationship between neighbourhood walkability and walking bouts performed within the neighbourhood.

Findings reported here and in similar activity—BE studies offer an alternative to individual-level interventions focusing on behaviour change constructs that have failed to stem the related epidemics of physical inactivity, obesity and chronic disease across the US population. Instead, our findings support the concept that population health is a function of environmental and policy influences affecting the lives of all people.\textsuperscript{41}–\textsuperscript{45} Increasingly, policy-makers and practitioners are embracing multi-level interventions focusing on real-world environmental changes that facilitate or hinder health behaviour change and can lead to notable changes in health outcomes at the population level.

Limitations

The major limitation of the present study is that our sample of twins was mostly white and non-Hispanic, with education and income levels higher than the US population average, therefore study findings may not be generalizable to other sociodemographic groups. In addition, there were differences between the excluded and analytic samples in terms of income-level distribution and walkability, which could have led to sample bias. Specifically, the proportion of participants in the analytic sample with incomes in the US$80k–US$89.9k category was higher, and in the US$90k–US$99.9k, US$100k–US$149.9k and US$150k+ categories were lower, than in the excluded sample. These differences may have contributed to the difference noted between samples with respect to walkability, whereby the participants with higher incomes may be living in areas with higher walkability, which may in turn influence the amount of physical activity in which they engage. Although we used robust methods to control for familial confounds and included other important sociodemographic factors in statistical models, twin designs cannot control for all confounding and the cross-sectional study design precludes casual inferences. Finally, our study was limited to one geographic area of the USA; findings would need to be replicated in other settings (eg, rural areas, small towns).

Conclusions

Neighbourhood walkability was associated with objectively measured walking, both between and within twin pairs, providing evidence of a ‘quasicausal’ association between an important environmental exposure and health behaviour. Improvements to the BE could potentially lead to increased physical activity levels in communities throughout the USA.

Contributors

GED: conceptualisation, funding acquisition, methodology, supervision, validation and writing—original draft preparation. PH: data curation, funding acquisition, investigation, methodology, software, validation, visualisation and writing—review and editing. AV-M: funding acquisition, methodology, supervision, validation and writing—review and editing. AAA: data curation, investigation, project administration, validation, visualisation and writing—review and editing. ST: formal analysis, software, validation, visualisation and writing—review and editing. GED is the author serving as guarantor.

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Competing interests

None declared.

Patient and public involvement

Patients and/or the public were not involved in the design, or conduct, or reporting, or dissemination plans of this research.

Patient consent for publication

Not applicable.

Ethics approval

This study involves human participants and was approved by Washington State University IRB #14547. Participants gave informed consent to participate in the study before taking part.

Provenance and peer review

Not commissioned; externally peer reviewed.

Data availability statement

Data are available upon reasonable request. The data supporting the results of the present study are owned by the Washington State Twin Registry (WSTR). Thus, the data cannot be publicly shared as it involves third-party data. However, researchers wanting to gain access to the data can do so by contacting the WSTR and completing the appropriate forms stipulated in the WSTR Policies & Procedures guidelines. Application information can be sent to the Scientific Operations Manager at the following URL (https://wstwinregistry.org/contact-us/) or via email (ws.twinregistry@wsu.edu).

Supplemental material

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