# Neighborhood Walkability and the Walking Behavior of Australian Adults

Neville Owen, PhD, Ester Cerin, PhD, Eva Leslie, PhD, Lorinne duToit, MS, Neil Coffee, MA, Lawrence D. Frank, PhD, Adrian E. Bauman, MB.BS, MPH, PhD, FAFPHM, Graeme Hugo, PhD, Brian E. Saelens, PhD, James F. Sallis, PhD

**Background:** The physical attributes of residential neighborhoods, particularly the connectedness of streets and the proximity of destinations, can influence walking behaviors. To provide the evidence for public health advocacy on activity-friendly environments, large-scale studies in different countries are needed. Associations of neighborhood physical environments with adults' walking for transport and walking for recreation must be better understood.

**Method:** Walking for transport and walking for recreation were assessed with a validated survey among 2650 adults recruited from neighborhoods in an Australian city between July 2003 and June 2004, with neighborhoods selected to have either high or low walkability, based on objective measures of connectedness and proximity derived from geographic information systems (GIS) databases. The study design was stratified by area-level socioeconomic status, while analyses controlled for participant age, gender, individual-level socioeconomic status, and reasons for neighborhood self-selection.

**Results:** A strong independent positive association was found between weekly frequency of walking for transport and the objectively derived neighborhood walkability index. Preference for walkable neighborhoods moderated the relationship of walkability with weekly minutes, but not the frequency of walking for transport—walkability was related to higher frequency of transport walking, irrespective of neighborhood self-selection. There were no significant associations between environmental factors and walking for recreation.

**Conclusions:** Associations of neighborhood walkability attributes with walking for transport were confirmed in Australia. They accounted for a modest but statistically significant proportion of the total variation of the relevant walking behavior. The physical environment attributes that make up the walkability index are potentially important candidate factors for future environmental and policy initiatives designed to increase physical activity.
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## Introduction

Promoting participation in moderate-intensity physical activity is a public health priority.[1,2] Walking is the most common moderate-intensity activity of adults, and is associated with substantial health benefits.[3,4] Both walking for transport and walking for recreation or exercise can contribute significantly to adults' total physical activity.[5,6] Improved understanding of the correlates of walking for each of these purposes can lead to evidence-based policies and programs; and ecologic models[7,8] indicate that personal, social, and physical environment factors all should be taken into account.[9–13] National[1,2] and international[14,15] agencies have identified built-environment and policy changes as essential for increasing walking and physical activity.

Systematic reviews have concluded that built-environment attributes, especially land-use patterns, are consistently related to physical activity in general and to active transportation in particular.[16,17] Different correlates of walking for transport and walking for recreation and exercise have been identified. Reviews of the health literature indicate that access to recreation facilities and the aesthetics of activity settings are related to recreational physical activity and to walking.[10,15] Re-

From the Cancer Prevention Research Centre, School of Population Health (Owen, duToit), The University of Queensland, Brisbane, Australia; Institute of Human Performance, The University of Hong Kong (Cerin), Hong Kong; School of Health and Social Development, Deakin University (Leslie), Geelong, Victoria, Australia; National Centre for Social Applications of GIS, Australian Institute of Social Research, The University of Adelaide (Coffee, Hugo), Adelaide, Australia; School of Community and Regional Planning, University of British Columbia (Frank), Vancouver, Canada; Centre for Physical Activity and Health, School of Public Health, The University of Sydney (Bauman), Sydney, Australia; University of Washington School of Medicine and Children's Hospital and Regional Medical Center (Saelens), Seattle, Washington; Department of Psychology, San Diego State University (Sallis), San Diego, California

Address correspondence and reprint requests to: Neville Owen, PhD, Cancer Prevention Research Centre, School of Population Health, The University of Queensland, Herston Road, Herston QLD 4006, Australia. E-mail: n.owen@sph.uq.edu.au.



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views of the transportation research and urban planning literature indicate that ease of pedestrian access to nearby destinations is related to active transportation choices, particularly walking.[12,16,17]

Key elements of neighborhood walkability are proximity and connectivity.[12,18–21] Proximity is related to mixed-land uses that create shorter distances between residences and destinations such as stores or work places. Connectivity is the directness and variety of routes to destinations, typically as a result of grid patterns of interconnecting streets. These elements are synergistic, determine distances between complementary activities, and can be assessed objectively using geographic information systems (GIS) software.[22,23]

Social and demographic attributes must be taken into account when examining how environments might be related to walking, as such factors may act to moderate the relationship between walkability and walking behavior. Gender, age, and socioeconomic status (SES) are consistently related to physical activity.[5,6,8] Age is inversely related to most types of physical activity, but associations with other sociodemographic attributes can vary by type and purpose of physical activity. For example, relative to men, women do more moderate-intensity activity and less vigorous activity. Those of higher SES tend to be more active in their leisure time, but walking for transportation can be higher in lower-SES groups with less access to cars and who use transit more frequently.[5]

A criticism of studies on environment–walking relationships is their failure to control for neighborhood self-selection bias.[16] It is argued that individuals self-select neighborhoods that reflect their underlying preferences for activity; thus, an association between environment and activity may be a reflection of that underlying individual preference. Thus, neighborhood selection might act to moderate the relationship between walkability and walking behavior. Underlying preferences for being physically active or able to walk to destinations need to be taken into account to isolate the impact of the built environment on walking and other health-related outcomes. In recent studies of travel behavior, walkability attributes of neighborhoods were independently related to active transportation, after controlling for preferences for living in neighborhoods with such attributes.[24–26]

Relationships were examined among objectively determined neighborhood walkability attributes with adults' walking for transport in an Australian city, controlling for the influence of socioeconomic attributes and for neighborhood self-selection. Consistent with a behavior-specific ecologic perspective,[9–13] and in order to highlight the potential specificity of the relevant associations, it was predicted that neighborhood walkability would be more strongly related to walking for transport than to walking for recreation.

## Methods

### Study Design and Participants

The PLACE study (Physical Activity in Localities and Community Environments) was designed to compare physical activity levels of residents with similar SES characteristics who lived in high- or low-walkable areas. The design also allowed for the examination of how built-environment variables might operate differently for people in high- and low-SES contexts. Few studies to date have examined such SES differences. This study used a stratified multistage cluster sampling strategy adapted from the study design and measurement protocols of the Neighborhood Quality of Life Study (NQLS) in the United States.[27] Methods were modified for the Australian setting, particularly by using the relevant elements of Australian Bureau of Statistics (ABS) Census data and GIS databases (see below). The study was conducted in Adelaide, a city of 1.3 million residents and an area of 1827 km$^2$, with approval from the Behavioral and Social Sciences Ethics Committee of the University of Queensland.

Thirty-two neighborhoods were selected from 2078 urban Census Collectors' Districts in the Adelaide Statistical Division. These districts are the smallest data-collection and reporting unit used by the ABS, with approximately 250 households per district, where income, ethnicity, and other demographic factors are reported. Selected neighborhoods included clusters of three to nine adjacent Collectors' Districts (each was made up of some 250 households) that could be identified as high- or low-walkable using GIS data, and then selected as high- or low-SES, based on Census data. The study design resulted in an equal number ($n$=8) of neighborhoods stratified as follows: high walkable/high SES, high walkable/low SES, low walkable/high SES, and low walkable/low SES, and totaling 156 districts.

Households within neighborhoods were then selected using simple random sampling, without replacement. Eligible respondents were English-speaking adults, aged 20 to 65 years, who resided in private dwellings such as houses, apartments, or units, and who were able to walk without assistance. In households with more than one potentially eligible participant, the individual with the most recent birthday was asked to complete the study questionnaire.

Participant recruitment and data collection were handled by mailed surveys in a series of waves, between July 2003 and June 2004, in order to obtain data from respondents across the range of seasons, in a city with a Mediterranean climate where summer days could be occasionally quite warm (35°–40°C [95°–104°F]), but where minimum winter temperatures were generally well above 0°C (32°F). A total of 2650 eligible participants from 154 districts returned the questionnaire. Participant sociodemographic characteristics are shown in Table 1. A more detailed account of the recruitment methods and outcomes is reported elsewhere.[28]

### Measures

Measures used were identified as either district-level variables (derived from either GIS databases, or from census data), or as individual-level variables (derived from participants' responses to survey items).

**Walkability index (district-level variable).** A walkability index was calculated at the district level, using GIS methods, using

**Table 1.** Characteristics of neighborhoods selected and individual characteristics of residents recruited from these neighborhoods

| | | Types of neighborhoods | | | |
|---|---|---|---|---|---|
| **Variable** | **All** | **High-walkable/ high-SES** | **High-walkable/ low-SES** | **Low-walkable/ high-SES** | **Low-walkable/ low-SES** |
| **CD-LEVEL** | | | | | |
| **Walkability index** | | | | | |
| Mean | 23.3 | 31.3 | 26.9 | 15.4 | 20.3 |
| SD | 7.9 | 4.2 | 4.6 | 4.9 | 5.8 |
| Range | 6–38 | 17–38 | 13–17 | 7–33 | 6–31 |
| **Weekly household income (%)** | | | | | |
| $ 1–499 | 20.4 | 6.6 | 38.8 | 1.1 | 36.8 |
| $ 500–999 | 63.4 | 68.3 | 61.2 | 60.8 | 63.2 |
| $ >999 | 16.1 | 25.1 | 0.0 | 38.1 | 0.0 |
| **INDIVIDUAL LEVEL** | | | | | |
| **Age (%)** | | | | | |
| 20–29 | 14.6 | 20.3 | 15.4 | 9.8 | 13.3 |
| 30–44 | 32.7 | 30.9 | 35.9 | 31.0 | 33.5 |
| 45–65 | 50.8 | 47.1 | 47.1 | 57.2 | 51.0 |
| Missing | 1.9 | 1.7 | 1.6 | 2.0 | 2.2 |
| **Gender (%)** | | | | | |
| Male | 35.6 | 37.5 | 34.9 | 37.1 | 32.6 |
| Female | 63.6 | 61.9 | 64.5 | 62.1 | 66.2 |
| Missing | 0.8 | 0.6 | 0.6 | 0.8 | 1.2 |
| **Education (%)** | | | | | |
| Year 10 or below | 23.3 | 6.2 | 30.7 | 20.8 | 36.8 |
| Year 12 or equivalent | 29.5 | 18.3 | 32.5 | 31.0 | 36.5 |
| Tertiary | 45.5 | 74.3 | 34.6 | 47.0 | 24.6 |
| Not stated | 1.7 | 1.2 | 2.3 | 1.3 | 2.2 |
| **In paid labor force (%)** | | | | | |
| Yes | 60.8 | 70.8 | 55.5 | 67.4 | 48.4 |
| No | 36.9 | 27.5 | 41.6 | 31.1 | 48.2 |
| Missing | 2.3 | 1.7 | 2.9 | 1.5 | 3.4 |
| **Annual household income (%)** | | | | | |
| $1–31,199 | 35.4 | 21.5 | 47.9 | 22.2 | 35.4 |
| $32,000–77,999 | 40.7 | 42.9 | 37.9 | 45.5 | 40.7 |
| $>77,999 | 19.2 | 31.5 | 7.7 | 29.6 | 19.2 |
| Missing | 4.7 | 4.1 | 6.5 | 2.7 | 4.7 |
| **Children in household (%)** | | | | | |
| Yes | 30.5 | 18.6 | 28.2 | 35.6 | 39.4 |
| No | 66.5 | 79.1 | 67.5 | 61.6 | 57.8 |
| Missing | 3.0 | 2.3 | 4.3 | 2.8 | 2.8 |

CD, Collector's Districts.

four environmental attributes found to be related to walking: dwelling density, street connectivity, land-use mix, and, net retail area.[19,22,23] Street centerline data, land use, zoning data, shopping center location data, and census data were spatially integrated within a GIS to create a composite measure (the walkability index) based on the relevant environmental attributes for each district. The methods for calculating the walkability index on which those used in the present study were based have been reported elsewhere.[29] In summary, after computation, each of the four component variables making up the walkability index (dwelling density, street intersection density, land use, and net retail area) was classified into deciles to provide a standard score from 1 to 10, with 1 indicating low walkability and 10 indicating high walkability. The walkability index was derived through summing these decile scores, resulting in a possible score of 4 to 40. In order to identify areas that were well-differentiated in their walkability attributes, the resulting walkability index was further classified into quartiles, with the 1st quartile used to identify low-walkable districts and the 4th quartile to identify high-walkable districts. Similar walkability indexes have been related to physical activity variables in studies conducted in the Atlanta GA[30] and Seattle WA regions,[27] supporting validity and generalizability.

**Socioeconomic status (district-level variable).** Once all districts representing the highest 25% and lowest 25% of the walkability index had been identified, the SES attributes of these areas were determined using census data for all of the districts selected. SES might act as a significant confounding factor in environment–behavior studies on physical activity.[18,31] The ABS 2001 Census of Population and Housing was the main SES data source,[32] and median household income was used as the primary SES indicator. Some districts with high proportions of retirees were excluded, as such areas can be lower in income, but rich in assets.[32] Ethnicity is not typically used as an element of sociodemographic selection in Australia.[33]

**Measures of walking (individual-level variable).** Walking for transport and walking for recreation were measured using relevant items and scoring rules from the International Physical Activity Questionnaire–Long Form (IPAQ).[34] This instrument is designed for use by adults, and the Long Form assesses physical activity that is specific to domains, including transport-related and leisure-time walking.[34] Using IPAQ data, walking scores (in minutes per week) are computed from items measuring frequency in the past week (days) and usual duration per day (hours and minutes). The reliability and validity of the instrument has been tested across 12 countries.[35] Weekly frequency and weekly minutes of walking, separately for transport, and for recreation were computed. Street connectivity and living close to destinations could lead to more frequent walking trips, so frequency could be a sensitive outcome of walkability; however, the volume of walking time is more important for health and should also be examined.

**Sociodemographic attributes (individual-level variables).** Respondents provided information on age, gender, educational attainment, household income, the presence of children in the household, and employment status.

**Neighborhood self-selection (individual-level variable).** Respondents were asked to report on a 5-point Likert-type scale, the perceived importance of the following reasons for selecting their neighborhood: closeness to job or school, closeness to public transportation, desire for nearby shops and services, and ease of walking. Neighborhood self-selection was computed as the average rating on these four items. The neighborhood selection index used in the present study was adapted from the Strategies for Metropolitan Atlanta's Regional Transportation and Air Quality (SMARTRAQ) study.[29]

### Analyses

The original aim of the PLACE study was to examine differences in walking behavior among residents of four types of neighborhoods (high walkable/high SES, high walkable/low SES, low walkable/high SES, and low walkable/low SES). However, preliminary analyses conducted in 2006 showed that the four types of neighborhoods were not as distinctly separated on walkability or on SES scores, as originally had been intended in the study design. This came about because there were practical compromises necessary with neighborhood selection, in order to meet study design criteria of having clusters of contiguous Collectors' Districts (CD). Thus, it was not possible to have "pure" clusters that were uniformly high or low on both SES and walkability. To deal with this, multilevel models were used to examine the independent associations between weekly frequency and minutes of walking as a function of the walkability index (treated as a continuous variable for each district); neighborhood socioeconomic status (operationalized as three categories of median weekly household income of each CD); and self-reported sociodemographic variables (age, gender, educational attainment, annual household income, and children in the household). In these analyses, district-level attributes (SES and walkability) were treated as level-2 variables; individual-level attributes were treated as level-1 variables.

The neighborhood self-selection variable was subsequently added to the models to examine the independent effects of walkability on walking behavior. A final set of models examined the moderating effects of sociodemographic factors, neighborhood SES, and neighborhood self-selection on the relationships between neighborhood walkability and walking behaviors. Standard error estimates adjusted for the nonnormal distribution of the data were used.[36] For all analyses, a probability level of 0.05 was adopted. Analyses were conducted using SPSS version 13.0 and MLwiN version 2.02.

## Results

The final overall response rate (from all households initially identified in the spatially-derived sampling frame) was 11.5%, and ranged from 10.5% in the low-SES communities to 12.8% in the high-walkable, high-SES neighborhoods. Response rates did not differ significantly by study quadrant. The return rate of respondents completing the survey, as a proportion of those known to be contacted, was 74.2%. Table 1 shows the attributes of survey respondents. Compared to the 2001 ABS Census data,[32] survey respondents were more likely to be older, female, and in paid work (all $\chi^2$ tests significant at $p<0.01$).

### Amount of Time and Frequency of Weekly Walking

Survey respondents reported, on average, 185 weekly minutes of walking for transport (median=90; SD=285) and 125 weekly minutes of walking for recreation or exercise (median=60; SD=220). Analysis of variance components showed that all of the variance in weekly minutes of walking for recreation or exercise was attributable to individual differences. In contrast, approximately 1.3% of the total variance of weekly minutes of walking for transport was due to differences among districts.

On average, walking for transport was reported on 3.3 days of the week (median=3; SD=2.6) and walking for recreation on 2.0 days of the week (median=1; SD=2.3). The district-level variance of weekly frequency of walking for recreation or exercise was 1.0%. Some 4.7% of the total variance of weekly frequency of walking for transport was due to district-level differences.

### Walking as a Function of Objective Walkability and Neighborhood SES

For weekly minutes of walking for transport, there were no significant effects of objective walkability and neighborhood SES after adjusting for individual-level sociodemographic factors (Table 2, Models 1 and 2). Walk-

**Table 2.** Multilevel linear regression models for predictors of weekly minutes of walking for transport

| | Model 1 | | | Model 2 | | |
|---|---|---|---|---|---|---|
| **Explanatory variables** | **b (SE)** | **Wald test (df)** | ***p*** | **b (SE)** | **Wald test (df)** | ***p*** |
| **Age** | −0.3 (0.5) | 0.4 (1) | 0.517 | −0.3 (0.5) | 0.3 (1) | 0.603 |
| **Gender** | | | | | | |
| (ref.: Male) | | 0.9 (1) | 0.353 | | 3.3 (1) | 0.071 |
| Female | −11.4 (12.6) | | | −22.5 (12.5) | | |
| **Educational attainment** | | | | | | |
| (ref: Yr 10 or below) | | 0.3 (2) | 0.842 | | 0.4 (2) | 0.832 |
| Yr 12 or equivalent | 6.2 (18.4) | | | 8.8 (16.6) | | |
| Tertiary | 9.6 (17.1) | | | 9.3 (16.4) | | |
| **Children in household** | | | | | | |
| (ref: No) | −19.3 (12.5) | 2.1 (1) | 0.143 | −20.6 (13.2) | 2.4 (1) | 0.118 |
| **Annual household income** | | | | | | |
| (ref: $ 1–31,999) | | 14.0 (2) | <0.001 | | 10.5 (2) | 0.005 |
| $ 32,000–77,999 | −46.6 (13.2) | | | −41.1 (13.9) | | |
| >$ 77,999 | −54.9 (15.8) | | | −46.8 (17.7) | | |
| **CD-level SES** | | | | | | |
| (median weekly household income; ref: $ 1–499) | | 2.7 (2) | 0.264 | | 2.5 (2) | 0.293 |
| $ 500–999 | −22.4 (15.4) | | | −22.1 (16.2) | | |
| $ >999 | −32.5 (19.4) | | | −30.5 (21.3) | | |
| **Walkability index** | 1.2 (0.8) | 2.3 (1) | 0.129 | 0.7 (0.8) | 0.7 (1) | 0.406 |
| **Neighborhood self-selection** | — | — | — | 29.8 (5.9) | 25.8 (1) | <0.001 |
| **Intercept** | 240.1 (19.3) | 154.6 (1) | <0.001 | 242.7 (19.3) | 158.2 (1) | <0.001 |

*Note:* Age, walkability index, and neighborhood self-selection were centered on the grand mean.
CD, Collector's Districts; MLR, multilevel linear regression; MPR, multilevel Poisson regression; SE, significant error; SES, socioeconomic status.

ability explained 1.4% of the outcome variance. Individual-level household income and neighborhood self-selection were the only significant independent predictors of weekly minutes of walking for transport ($p<0.001$). Higher household income was associated with less walking, while choosing to live in a specific neighborhood because of its access to services was predictive of more weekly minutes of walking for transport.

Weekly frequency of walking for transport was independently related to neighborhood walkability, individual-level household income, having a child in the household, neighborhood self-selection (all $p<0.001$), and gender ($p=0.052$ and $p<0.001$; Table 3, Models 1 and 2). Being female, having a child in the household, and having a higher household income were negatively associated with weekly frequency of walking for transport, while neighborhood walkability and neighborhood self-selection were independently positively associated. Walkability explained approximately 4.2% of the variance in frequency of walking for transport.

Weekly minutes and weekly frequency of walking for recreation were independently associated with age and having a child in the household (all $p<0.01$) and with neighborhood self-selection ($p<0.05$). That is, older respondents, with no children in the household, and those choosing their neighborhood because of its access to services walked more for recreation than did their counterparts. No statistically significant relationships between neighborhood walkability and walking for recreation were found.

## Moderators of Relationships Among Neighborhood Walkability Attributes with Walking Behaviors

Neighborhood self-selection was the only significant moderator of the relationship between neighborhood walkability and weekly minutes of walking for transport ($\beta=1.59$; SE=0.73; Wald test: $\chi^2[1]=4.78$; $p=0.029$). No significant effect of neighborhood walkability on weekly minutes of walking for transport was observed among residents for whom access to services was not an important reason for living in their neighborhood. In contrast, neighborhood walkability was associated with more walking for transport in residents for whom access to services was an important reason for living in a specific neighborhood. For these residents, living in areas with a walkability index that was one standard deviation above the average was associated with 37 minutes more walking than living in areas with a walkability index that was one standard deviation below the average.

Educational attainment moderated the relationship between weekly frequency of walking for transport and neighborhood walkability ($\beta_1=0.014$; SE=0.005; $\beta_1=0.015$; SE=0.004; Wald test: $\chi^2[2]=12.96$; $p=0.002$).

**Table 3.** Multilevel Poisson regression models for predictors of weekly frequency of walking for transport

| | Model 1 | | | Model 2 | | |
|---|---|---|---|---|---|---|
| **Explanatory variables** | **b (SE)[a]** | **Wald test (df)** | ***p*** | **b (SE)[a]** | **Wald test (df)** | ***p*** |
| **Age** | 0.00 (0.01) | 0.1 (1) | 0.707 | 0.00 (0.01) | 0.4 (1) | 0.830 |
| **Gender** | | | | | | |
| (ref.: Male) | | 3.8 (1) | 0.052 | | 12.6 (1) | <0.001 |
| Female | −0.05 (0.02) | | | −0.09 (0.03) | | |
| **Educational attainment** | | | | | | |
| (ref: Yr 10 or below) | | 2.9 (2) | 0.230 | | 4.5 (2) | 0.106 |
| Yr 12 or equivalent | 0.03 (0.03) | | | 8.8 (16.6) | | |
| Tertiary | 0.06 (0.03) | | | 9.3 (16.4) | | |
| **Children in household** | | | | | | |
| (ref: No) | −0.10 (0.03) | 11.9 (1) | <0.001 | −0.11 (0.03) | 14.5 (1) | <0.001 |
| **Annual household income** | | | | | | |
| (ref: $ 1–31,999) | | 30.0 (2) | <0.001 | | 18.3 (2) | <0.001 |
| $ 32,000–77,999 | −0.12 (0.03) | | | −0.10 (0.03) | | |
| >$ 77,999 | −0.18 (0.04) | | | −0.14 (0.04) | | |
| **CD-level SES** | | | | | | |
| (median weekly household income; ref: $ 1–499) | | 1.4 (2) | 0.497 | | 2.1 (2) | 0.359 |
| $ 500–999 | −0.04 (0.05) | | | −0.04 (0.05) | | |
| $> 999 | 0.02 (0.07) | | | −0.03 (0.06) | | |
| **Walkability index** | 0.02 (0.01) | 37.6 (1) | <0.001 | 0.01 (0.00) | 29.1 (1) | <0.001 |
| **Neighborhood self-selection** | — | — | — | 0.13 (0.01) | 109.9 (1) | <0.001 |
| **Intercept** | 1.31 (0.05) | 692.0 (1) | <0.001 | 1.30 (0.05) | 742.0 (1) | <0.001 |

*Note:* Age, walkability index, and neighborhood self-selection were centered on the grand mean.
[a]Natural logarithms of weekly frequency of walking for transport.
CD, Collector's Districts; SES, socioeconomic status.

There was no significant effect of neighborhood walkability on frequency of walking for transport in respondents with 10 or less years of education. In contrast, a positive significant association was found between walkability and frequency of walking for transport in respondents with 12 or more years of education.

No statistically significant moderators of the relationship between neighborhood walkability and walking for recreation were found.

## Discussion

This large-scale Australian study supported previous findings.[10,12,16,17] Attributes of neighborhoods that include street connectivity and proximity to retail and commercial destinations were associated with residents' walking for transport, but not with walking for recreation. Walking for recreation was retained in the analyses, in order to highlight the potential specificity of the relevant associations with walking for transport. Environmental attributes were expected to have domain-specific associations with walking.[10,12]

The relationship between neighborhood walkability and walking for transport was stronger for weekly frequency than it was for weekly minutes. While more-walkable neighborhoods may encourage frequent walking for transport, they required shorter walking trips to reach destinations than did less-walkable neighborhoods. These results suggested that those who live in more-walkable environments might tend to make more frequent trips to nearby destinations (for example, the neighborhood grocery store), which might reduce motor vehicle trips. According to the present analyses, neighborhood walkability did not contribute to more minutes of transport walking, suggesting a limited physical activity effect. The weaker findings for total weekly minutes of walking for transport might result from there being greater measurement error for reported minutes, than there is for frequency of walking.

The findings are somewhat in contrast to those from the NQLS in the U.S., in which a significant association was found between a similarly-operationalized walkability index and weekly minutes of transportation-related physical activity (cycling and walking).[27] These differences among studies might be due in part to the superior metric characteristics of the walkability index used in the NQLS study. Specifically, in PLACE, a walkability index was computed for each census collection district, while in NQLS it was computed for each respondent, using data from a 1-km network buffer of geocoded places of residence. Thus, the NQLS measure was more specific to each individual, and presumably more accurate. Also, there were differences in computation of the walkability index across studies. The land-use mix component of the NQLS walkability index was based on the distribution of building floor space across different uses. In PLACE, the same component was based on the distribution of land area across different uses. This could result in different outcomes, as, for example, a tall building might contain over a million square feet of office and commercial use on a one-acre (43,560 square foot) site. This possibility was not examined, as comparable building square-foot data were not available for the study region. It also could be that a wider range of neighborhood walkability exists in the two U.S. regions examined in NQLS, in comparison to the regions of the Australian city that was studied here.

Mixed support was found for the hypothesis that environment–walking associations might be explained by residents' self-selection to neighborhoods based on their walkability.[17,24] Neighborhood self-selection was found to be a moderator of the relationship between walkability and weekly minutes, but not frequency, of walking for transport. Perhaps those with a low preference for walkable neighborhoods are willing to walk short distances to destinations such as shops on a frequent basis, but those preferring walkable neighborhoods are willing to walk longer distances to destinations, resulting in more total minutes of walking. Prospective studies are needed in which residents are exposed to different levels of walkability over time, and changes in behavior are recorded. This would help to determine the relative effect sizes of self-selection and neighborhood attributes for explaining walking.

A moderating effect similar to that of neighborhood self-selection was observed for educational attainment, where only among more highly-educated residents were there positive associations with neighborhood walkability. Both of these moderating effects suggested interactive effects of individual and built-environment factors, which were predicted by ecologic models of health behavior.[9,13] A negative association was found between household income and walking for transport. This finding might be explained by the greater availability of motorized transport and time constraints (long working hours), and a preference for other types of physical activity among the more affluent.

No significant associations were found between neighborhood walkability and walking for recreation. These findings support the hypotheses of domain-specific associations between environments and physical activity,[9,10,12] as walkability has been conceptualized as the ability to walk to nearby destinations. The walkability index used in this study did not capture access to recreational destinations nor the quality of the pedestrian environment (e.g., sidewalk maintenance, aesthetics), and therefore it is not surprising that it did not explain walking for recreation. Subsequent studies should be designed to examine factors likely to be more conducive to recreational walking.

Study limitations included dependent variables that were based on self-reported measures. While the limitations of self-report must be acknowledged, it should be noted that items used were from a well-tested measure—IPAQ.[33,34] This questionnaire is a standard measure, but it was unable to differentiate walking that occurs within and outside the neighborhood of residence. The weekly minutes of total walking reported by study participants, compared to those reported in Australian population-based surveys,[5] appeared to be high. It is possible, therefore, that there might have been response bias in this study, with more active residents being more willing to take part. New measures have since been developed that allow assessment of walking in and out of the neighborhood.[37] The use of a GIS-based walkability index that was particularly pertinent to walking for transport meant that the capacities to predict walking for recreation were limited. Nevertheless, the contrasting associations with walking for transport and walking for recreation support hypotheses about the specificity of environment–behavior relationships.[9–13] Survey response rates within the spatially-based sampling frame were modest, but did not differ across the four study quadrants. The low response rate was a limitation of this study and potentially could introduce selection bias. Although it was equal across neighborhoods (thus not influencing the neighborhood variables), it could have a significant impact on the variability of the walking measures. The strengths of this study included the use of GIS databases to create an objective walkability index and to identify neighborhoods that maximized variation in walkability. The use of census data to identify localities of higher and lower socioeconomic status allowed simultaneous examination of walkability and SES effects.

From a methodologic viewpoint, this study highlights the difficulties associated with community stratification by walkability and SES. These two dimensions are associated, and thus it was difficult to study their independent effects via stratification. Compromises were made in arriving at the neighborhoods that were finally selected, and the desirable level of distinctiveness of walkability and SES attributes was not achieved among the four quadrants of the study design. Communities that are high SES/low walkability and low SES/high walkability can be difficult to identify (likely due to the positive association between SES and walkability), so it is necessary to consider this as one of the limitations of the findings.

These findings contribute to a rapidly developing body of knowledge on the environmental correlates of physical activity participation. The emerging pattern of results from such studies is now complex and challenging to synthesize, and there is evidence[38] that some findings have been reported inconsistently in recent review papers. This is an exciting new field of research. There have been significant developments in methodologies to assess the relevant environmental exposures[30,39] and some helpful conceptual distinctions among the different walking behaviors.[9,10,18] Also, additional specific-research domains are developing and differentiating; for example, there are recent studies of specific adult subgroups,[40] studies of transport infrastructure and walking behavior,[41] and, studies on relationships of children's physical activity to community design.[42]

These findings also add support to calls for policy initiatives to create more-walkable neighborhoods.[16,17] Living in more-walkable neighborhoods was found to be associated with a higher frequency of transport walking among residents, indicating that walkability associations seen primarily in the U.S.[16,17] also generalize to Australia. These findings extend those of previous studies. Those with higher education and who selected neighborhoods based on proximity of services reported more transport-related walking in the more-walkable areas. Thus, some population groups appear to benefit more from walkable neighborhoods. Further studies of interactions of individual factors and neighborhood environments are needed; there is a particular need for prospective studies of neighborhood self-selection and walkability effects.[43,44]

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