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Neighborhood walkability and hospital treatment costs: A first assessment

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ABSTRACT

Health system expenditure is a global concern, with hospital cost a major component. Built environment has been found to affect physical activity and health outcomes. The purpose of the study was a first assessment of the relationship between neighborhood walkability and hospital treatment costs. For 88 neighborhoods in the Australian Capital Territory (ACT), 2011–2013, a total of 30,690 public hospital admissions for the treatment of four diagnostic groups (cancers, endocrine, nutritional and metabolic diseases, circulatory diseases and respiratory diseases) were extracted from the ACT admitted patient care database and analyzed in relation to the Walk Score® index as a measure of walkability. Hospital cost was calculated according to the cost weight of the diagnosis related group assigned to each admission. Linear regressions were used to analyze the associations of walkability with hospital cost per person, admissions per person and cost per admission at the neighborhood level. An inverse association with neighborhood walkability was found for cost per person and admissions per person, but not cost per admission. After adjusting for age, sex and socioeconomic status, a 20-unit increase in walkability was associated with 12.1% (95% CI: 7.1–17.0%) lower cost and 12.5% (8.1–17.0%) fewer admissions. These associations did not vary by neighborhood socioeconomic status. This exploratory analysis suggests the potential for improved population health and reduced hospital cost with greater neighborhood walkability. Further research should replicate the analysis with data from other urban settings, and focus on the behavioral mechanisms underlying the inverse walkability-hospital cost association.

1. Introduction

Health care costs are rising globally. In 2013, OECD countries spent on average USD 3453 per person on health care (3866 for Australia; 8713 for the United States) (OECD, 2015). The average share of gross domestic product spent in health care increased from 6.1% in 1980 to 8.9% in 2013 (5.8% to 8.8% for Australia; 8.2% to 16.8% for the United States) (OECD, 2015). As non-communicable diseases (e.g., cancers, diabetes and cardiovascular and chronic respiratory diseases) have replaced infectious diseases as the leading cause of death worldwide (World Health Organization, 2014), people are likely to spend more years in need of health care for long-term illnesses and physical limitations.

Some of these chronic diseases are related to lifestyle risk factors such as inadequate physical activity. Growing research in the last 10–15 years has focused on the association between the built environment, physical activity (e.g. walking) and health. These studies found that people are more physically active when they live in walkable neighborhoods that have interconnected streets and diverse nearby destinations such as shops, restaurants, services, public transit stops and parks (Committee on Physical Activity, 2005; Renalds et al., 2010; Saelens et al., 2003). Built environment characteristics promoting or inhibiting physical activity are also associated with the prevalence and incidence of metabolic complications and chronic diseases such as obesity, diabetes and hypertension (Booth et al., 2011; Ewing et al., 2003; Sallis et al., 2012). These health conditions could require expensive medical care, in particular inpatient hospital treatment. To our knowledge, however, no studies have investigated the hospital cost impact of neighborhood walkability.

In this paper, we used hospital admissions data and a validated publicly available index of neighborhood walkability (Walk Score®) to conduct an aggregate-level cross-sectional analysis of the relationship between walkability and inpatient hospital costs in the Australian Capital Territory (ACT). Comprehensive public hospital admissions for four primary medical diagnosis groupings (cancers; endocrine, nutritional and metabolic [ENM] diseases; circulatory diseases; and respiratory diseases) were analyzed. We examined the association of neighborhood walkability with hospital cost per person and its two components (the

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number of hospital admissions per person and cost per admission). In analyzing the two separate components, an additional question was to determine the extent to which these two components drive the association between walkability and hospital cost. We further asked whether the walkability-cost association is explained or varies by neighborhood socio-economic conditions. Finally, estimates were derived for hypothetical changes in hospital outcomes, given changes in walkability. By exploring and analyzing associations between hospital costs and walkability, this study extends the existing literature on built environment and health outcomes, and informs policies to facilitate and promote healthier lifestyles to reduce health care cost.

2. Methods

The study population was Australia's capital city Canberra, in which around 380,000 people reside (Australian Bureau of Statistics, 2015a). Acute hospital admissions in the region's two public hospitals between 2011 and 2013 were extracted from the administrative database of admitted patient care maintained by the ACT Government Health Directorate. For each admission, the database includes standard socio-demographic information such as age and sex, location of residence, dates of admission and separation, and clinical information such as medical diagnosis, type of care, and the Australian Refined Diagnosis Related Group (AR-DRG). The AR-DRG codes relate the type of patients to the hospital resources required for treatment (Australian Institute of Health and Welfare, 2014a).

Cases were selected where the primary medical diagnosis was coded according to the 10th Revision of the International Classification of Diseases as one of the four groups: cancers (C00-D48), ENM diseases (E00-E88), circulatory diseases (I00-I99), and respiratory diseases (J00-J98). These are among the chronic conditions contributing the greatest burden to hospital costs in ACT and Australia (Australian Institute of Health and Welfare, 2014a). The study was approved by the ACT Health Human Research Ethics Committee on 10 December 2014 (Protocol: ETH.11.14.310) and the University of Canberra Human Research Ethics Committee (Protocol: 12-158).

We defined neighborhood at the suburb level, that is, Statistical Areas Level 2 in the Australian Statistical Geography Standard (Australian Bureau of Statistics, 2011a). A suburb in Australia generally has a population size ranging from 3000 to 25,000, with an average of about 10,000. In the ACT, they are smaller with population sizes between 1000 and 15,000. Of the 31,800 acute-care admissions due to the four diagnosis groups between 2011 and 2013, the following data were excluded: 228 records with missing information on statistical area or neighborhood walkability, 804 records in four new suburbs that were built and settled in 2010 or later, and 78 records in two suburbs with very low total admission numbers. The final analysis data had a total of 30,690 hospital admissions and included 88 ACT suburbs. Note that these were the *total* of acute care admissions to public hospitals for the treatment of the four disease categories, except for the above exclusions. However, private hospital admissions were not available for the ACT (Australian Institute of Health and Welfare, 2014a), a limitation that we further consider in the Discussion section.

Also note that our analysis included patients for the treatment of *all diseases* classified under the four diagnostic categories. This was because current knowledge on built environment features and disease outcomes was not sufficient for us to select or exclude admissions. While there has been considerable evidence linking built environment with CVD and risk factors and diabetes, neighborhood walkability could affect the prognosis of other less well-known illnesses. In addition, given the large body of research on the developmental origins of chronic diseases (Gluckman and Hanson, 2006), we analyzed admissions at *all ages*, including infants who were not ready to walk. However, additional sensitivity analyses (not shown) found essentially identical results when we excluded 1473 admissions for ENM diseases that were not diabetes (that is, ICD-10 codes E00-E88, except E10-E14) and 2037 admissions under age 5.

2.1. Hospital cost measures

We constructed three outcome measures: annual hospital cost per person and its two components of admissions per person and cost per admission. All three outcomes were aggregated at the neighborhood level and adjusted for age and sex using the direct standardization method. In addition to the hospital admissions data, we used the 2011–2013 age-sex-specific midyear population estimates for each neighborhood as population exposure (that is, denominator) (Australian Bureau of Statistics, 2015b) and the midyear 2013 Australian age-sex population distribution as the standard (Australian Bureau of Statistics, 2015a).

The outcome of cost per person was derived in three steps. First, we used the cost weights associated with the AR-DRG codes of hospital admissions to determine the cost for each hospital admission. We used the public hospital cost weights for AR-DRG version 6.0x: Round 16 for admissions in 2011 (Independent Hospital Pricing Authority, 2014) and Round 17 for admissions in 2012–2013 (Independent Hospital Pricing Authority, 2015), and then adjusted the cost to 2013 Australian dollars, using an adjustment factor (Australian Institute of Health and Welfare, 2014b). Second, for each neighborhood, we summed the cost within sex and age groups (under age 5, eight 10-year groups and 85+) and divided it by midyear population to calculate cost per person. Last, we weighted the actual age-sex-specific hospital cost by the standard population to get age-sex-standardized cost per person for each neighborhood. The admissions per person outcome was calculated in the same steps, but counting the number of admissions instead of adding up the cost. The cost per admission outcome was derived by dividing cost per person by admissions per person (that is, cost per admission = cost per person/admissions per person).

2.2. Walkability and socioeconomic status measures

We used Walk Score®, a publicly accessible index to measure neighborhood walkability (Walk Score®, 2015). Based on data sources such as Google, Open Street Map and other Walk Score® user provided information, the patented Walk Score® algorithm uses a decay function to award points for each geographic location by calculating the shortest network distance to amenities in each of 13 categories that include stores, restaurants, entertainment, schools and parks. The categories are equally weighted, and the points are summed and normalized to reach a score of 0–100, with penalties to account for less street interconnection. Higher Walk Score® values indicate more walkable neighborhoods. A five-category classification for Walk Score® was: 0–24 ("very car-dependent", almost all errands requiring a car), 25–49 ("car-dependent", most errands requiring a car), 50–69 ("somewhat walkable", some errands accomplishable on foot), 70–89 ("very walkable", most errands accomplishable on foot) and 90–100 ("walker's paradise", daily errands not requiring a car). The Walk Score® measure has been validated against geographic information system measures of neighborhood walkability (Carr et al., 2010, 2011; Duncan et al., 2011) and used previously in studies for various geographic locations and levels in Australia, Canada and the United States (e.g., Chiu et al., 2016; Cole et al., 2015; Sriram et al., 2016).

Neighborhood socioeconomic status (SES) was based on the Socioeconomic Indexes for Areas (SEIFA) developed by the Australian Bureau of Statistics, which are area-based composite measures of socioeconomic conditions, including income, educational attainment, employment or occupation and housing characteristics (Australian Bureau of Statistics, 2011b). In this analysis, we used the Index of Relative Socioeconomic Advantage and Disadvantage from the 2011 Census data, and based on preliminary analysis, grouped the rank scores of 0–100 into three categories: low (0–40), medium (41–80) and high (81–100).

2.3. Statistical analysis

We used linear regression to model the associations between neighborhood walkability and hospital treatment costs. Three models were estimated, sequentially adding 1) the Walk Score® variable, 2) the SES variable and 3) interactions between Walk Score® and SES. We modelled the outcomes on the logarithmic scale (owing to skewness in the distribution of these measures), the Walk Score® variable as continuous and the SES variable in the three categories detailed above. Model specification details are shown in Appendix A1.

The regression coefficient for the Walk Score® variable estimates the association between walkability and hospital outcomes. We interpret the exponential of the Walk Score® coefficient minus one as relative change in the outcome given a one-unit change in Walk Score®, and report this estimate along with 95% Confidence Interval (CI). Changes in the Walk Score® coefficient between Model 1 (unadjusted) and Model 2 (adjusted for SES) show the extent to which SES is responsible for the associations between walkability and hospital costs. Model 3 examines whether these associations vary across SES groups. Note that all models adjust for age and sex differences between the neighborhoods because the outcome measures have been age- and sex-standardized, as explained above.

Models 1–3 were estimated separately for each of the three outcomes. Recall cost is a product of the two component measures of admissions and cost per admission. Thus, the coefficient estimates on the logarithmic scale sum up. That is, the Walk Score® coefficient for the cost per person outcome is the sum of the two Walk Score® coefficients for admissions per person and cost per admission. We compared the estimates across the outcomes to gauge the role played by each component in the association between neighborhood walkability and hospital cost.

3. Results

Between 2011 and 2013, there were a total of 30,690 admissions for the four disease groups; hospital cost totaled AUD 251.8 million (Table 1). Circulatory and respiratory diseases took up the largest share of the admissions (39% and 33% respectively), followed by cancers 21%. The rate of admissions was high for those under age 5, dropping low between ages 5 and 35, and rising continuously from age 35 to the oldest ages. Hospital costs were higher for men than women, with men having a larger number of admissions, higher total cost, higher mean cost and higher standard deviation of cost.

Table 1
Descriptive statistics for acute public hospital admissions in the Australian Capital Territory, 2011–2013.

	Males	Females	Both sexes
Total hospital admissions[a]	16,338	14,352	30,690
Hospital cost (2013 AUD)			
Total (millions)[b]	142.5	109.2	251.8
Mean	8723	7611	8203
Standard deviation	11,602	9699	10,768
Distributions of medical diagnosis (%)			
Cancers	19	22	21
ENM[c] diseases	8	9	9
Circulatory diseases	42	35	39
Respiratory diseases	31	34	33
Age-specific rates of admissions (per 1000 persons)			
Aged 0–4 years	30.6	24.8	27.8
5–14	10.2	8.6	9.4
15–24	6.9	9.9	8.3
25–34	6.3	8.8	7.5
35–44	11.6	13.0	12.3
45–54	23.2	19.0	21.0
55–64	49.0	30.5	39.5
65–74	92.2	63.9	77.6
75–84	190.6	128.7	156.3
85+	279.7	192.9	223.2

[a] Admissions in 88 neighborhoods due to four diagnoses as listed.
[b] Male and female costs do not add up to the cost for both sexes because of rounding.
[c] ENM-endocrine, nutritional and metabolic.

Among the 88 neighborhoods, Walk Score® ranged between 15 and 83, with a mean value of 41, median of 38 and standard deviation of 14. As shown in Table 2, nearly four-fifths of the neighborhoods fell into the two car-dependent categories. Across the three SES categories, the low-SES neighborhoods were more likely to be in the two walkable categories than the medium- and high-SES ones: 13 out of the 35 low-SES neighborhoods were somewhat or very walkable, as compared with 4 out of the 39 medium-SES and 2 out of the 14 high-SES neighborhoods. However, the number of neighborhoods was small in the high SES-high walkability combinations. The correlation between the continuous Walk Score® and SES variables was negative 0.15 and statistically non-significant.

Regression estimates are shown in Table 3. Cost per person was inversely and statistically significantly associated with Walk Score®. The exponentiated coefficient in the unadjusted model indicates that a one-unit increase in Walk Score® was associated with a reduction in cost of 0.47% (0.13–0.80%). In Model 2 when the SES variable was included, the estimated cost reduction increased to 0.64% (0.36–0.92%). SES was also inversely associated with hospital cost; cost per person was lower for the higher than lower SES groups. In Model 3, the interaction terms between Walk Score® and SES on hospital cost were small and statistically non-significant, indicating that the inverse association between Walk Score® and cost did not vary across the SES categories. Results were not different when both SES and Walk Score® were specified as continuous (not shown).

Similar results were found when examining admissions per person. A one-unit Walk Score® increase was associated with a 0.52% (0.20–0.83%) reduction in admissions, which increased to 0.67% (0.41–0.92%) when SES was adjusted for, and the reduction in admissions was invariant across SES categories. However, cost per admission was not associated with Walk Score® in any of the three models.

Under the SES-adjusted model, percentage reductions in cost per person and admissions per person were nearly identical. Thus, the inverse association between neighborhood walkability and hospital cost was primarily driven by the smaller number of admissions in the more walkable neighborhoods, not by neighborhood differences in cost per admission.

Fig. 1 shows the raw data and SES-adjusted regression lines for the three log-transformed outcomes vs. Walk Score®, separate by SES. Cost per person and admissions per person were lower for higher Walk Score® values and higher SES groups. Cost per admission was not associated with Walk Score®; the estimates were lower for the medium SES group than for the low and high SES groups, but the differences were statistically non-significant (Table 3). The regression lines for the three SES groups were parallel with the same slopes, reflecting the lack of SES variations in the association between Walk Score® and hospital costs.

Based on the SES-adjusted models, we calculated percentage differences in hospital costs given Walk Score® differences of various magnitudes (Appendix A2). For a 20-unit Walk Score® increase, which roughly corresponds to changing from a less walkable to a more walkable neighborhood (e.g., from "very car-dependent" to "car-dependent" or from "car-dependent" to "somewhat walkable"), hospital cost would be lower by 12.1% (95% CI: 7.1–17.0%), and the number of admissions, smaller by 12.5% (8.1–17.0%). Applying these percentage reductions to the total hospital admissions for the four diagnoses over the three-year period (Table 1), the absolute reductions would reach AUD 30.5 (17.9–42.8) million and 3836 (2486–5217) admissions.

4. Discussion

Our analysis has found an association between walkability and hospital cost across 88 neighborhoods in the Australian Capital Territory.

Table 2
Walkability categories in relation to socioeconomic status, 2011–2013 ACT admitted patient care database.

	Walkability categories[a]				All neighborhoods
	Very car-dependent	Car-dependent	Somewhat walkable	Very walkable	
Total N (%)	4 (5%)	65 (74%)	13 (15%)	6 (7%)	88 (100%)
SES[b], N (%)					
Low	2 (6%)	20 (57%)	9 (26%)	4 (11%)	35 (100%)
Medium	1 (3%)	34 (87%)	3 (7%)	1 (3%)	39 (100%)
High	1 (7%)	11 (79%)	1 (7%)	1 (7%)	14 (100%)

[a] Based on Walk Score: "very car-dependent" (0–24), "car dependent" (25–49), "somewhat walkable" (50–69) and "very walkable" (70–89); no neighborhoods are "walker's paradise" (90–100).
[b] SES—socioeconomic status, based on rank scores for the Index of Relative Socioeconomic Advantage and Disadvantage: 0–40 (low), 41–80 (medium) and 81–100 (high).

People living in neighborhoods with a higher Walk Score® had lower average hospital cost for the acute care of four major chronic disease categories. The reductions in cost were mainly due to fewer hospital admissions (that is, lower rates of admissions), not to lower cost per admission in the more walkable neighborhoods. To our knowledge, this is the first empirical assessment of the relationship between neighborhood walkability and hospital costs. Strengths of the study include its population base (in a city of 380,000 people), comprehensive inclusion of admissions to public hospitals for four major chronic disease groups, validated index of neighborhood walkability, and analysis of hospital cost components. Study weaknesses include the observational and cross-sectional design, which has well-known limitations for inferring causal relationships. The analysis is at the aggregate level, thus not allowing for discerning the underlying individual behavioral mechanisms or uncovering heterogeneities within neighborhoods. Other limitations include missing information on duration of residence, and the composite walkability index does not measure neighborhood aesthetics and safety from traffic and crime that could also affect walking behavior and physical activities.

Table 3
Results from regressing hospital outcomes (logarithmic scale) on Walk Score®, 2011–2013 ACT admitted patient care database.

	Model 1		Model 2		Model 3	
	b	[s.e.]	b	[s.e.]	b	[s.e.]
Cost per person[a,b,c]						
Intercept	5.7869*	[0.0750]	6.0089*	[0.0712]	5.9983	[0.0959]
Walk Score (WS)	−0.0047*	[0.0017]	−0.0064*	[0.0014]	−0.0062*	[0.0020]
SES:[d] low as ref.						
Medium			−0.2016*	[0.0438]	−0.1868	[0.1480]
High			−0.3822*	[0.0588]	−0.3553*	[0.1614]
WS X SES:[e] low as ref.						
Medium					−0.0003	[0.0035]
High					−0.0007	[0.0037]
R^2	0.08		0.41		0.41	
Admissions per person[a,b]						
Intercept	−3.2292*	[0.0701]	−3.0350*	[0.0648]	−3.0999*	[0.0865]
Walk Score (WS)	−0.0052*	[0.0016]	−0.0067*	[0.0013]	−0.0052*	[0.0018]
SES:[d] low as ref.						
Medium			−0.1586*	[0.0399]	0.0025	[0.1334]
High			−0.3885*	[0.0535]	−0.3088*	[0.1454]
WS X SES:[e] low as ref.						
Medium					−0.0039	[0.0031]
High					−0.0018	[0.0033]
R^2	0.11		0.46		0.47	
Cost per admission[a,b,c]						
Intercept	9.0161*	[0.0400]	9.0439*	[0.0466]	9.0982*	[0.0619]
Walk Score (WS)	0.0005	[0.0009]	0.0003	[0.0009]	−0.0010	[0.0013]
SES:[d] low as ref.						
Medium			−0.0430	[0.0287]	−0.1892*	[0.0955]
High			0.0063	[0.0385]	−0.0465	[0.1041]
WS X SES:[e] low as ref.						
Medium					0.0036	[0.0022]
High					0.0012	[0.0024]
R^2	0.00		0.04		0.07	

* p-Value <0.05; s.e.—standard error; 100 − 100 ∗ exp(b) indicates % change in hospital outcome, given a one-unit change in the variable.
[a] Acute public hospital admissions in 88 ACT neighborhoods due to cancers, endocrine, nutritional & metabolic diseases, circulatory diseases & respiratory diseases.
[b] Directly age- and sex-standardized by using the 2013 Australian population as the standard.
[c] 2013 Australian dollar pricing.
[d] SES—socioeconomic status, based on rank scores for the Index of Relative Socioeconomic Advantage and Disadvantage: 0–40 (low), 41–80 (medium) and 81–100 (high).
[e] Interactions between WS and SES categories.

The lower hospital cost and smaller number of admissions associated with the higher Walk Score® in our analysis persisted after statistical adjustment for SES. Higher SES was associated with more favorable health outcomes (lower cost and fewer admissions), which is consistent with the established literature (Cutler et al., 2008; Smith, 2007). Interestingly, the more walkable neighborhoods were somewhat more likely to be of lower SES in the ACT, as was found for other international locations (Cowie et al., 2016; Creatore et al., 2016; King and Clarke, 2015). Since the SES and built environment variables were rather weakly correlated, and the more walkable ACT neighborhoods did not simultaneously have more socioeconomic resources, the inverse walkability-cost association was not attributable to SES differences across neighborhoods.

People living in neighborhoods with different walkability may differ in other ways, however. Even though we have accounted for SES, which is one of the most consistent characteristics associated with diverse health behaviors and outcomes, people could still self-select into residential areas based on physical activity and health status, for example. The inverse association of walkability with hospital admissions and cost could thus result from physically more active and healthier people having chosen to live in the more walkable neighborhoods. The ACT admissions database does not have the information to allow for a study design to disentangle self-selection from actual behaviors and make causal inference, as discussed above. However, the inverse association of neighborhood walkability with hospital costs was consistent with previous studies showing that people living in more walkable neighborhoods tend to engage more in physical activities, depend less on cars for everyday living and have lower risks of overweight and obesity and diabetes (Creatore et al., 2016; Duncan et al., 2014; Sallis et al., 2016). Most of the prior research was cross-sectional like ours (McCormack and Shiell, 2011). However, prospective studies comparing people moving to more or less walkable neighborhoods also found an inverse association of walkability with hypertension (Chiu et al., 2016) and body mass index increases among men (but not among women) (Wasfi et al., 2016).

The ACT admitted patient care database collected all admissions to the public hospitals, but because of confidentiality reasons, private hospital admissions were not available (Australian Institute of Health and Welfare, 2014a). In Australia, the majority of admissions occur in public hospitals, but there is a strong SES gradient between patients in public and private hospitals, and the type of care may also differ between the two. According to national statistics, of all admissions in 2012–2013, 41% occurred in private hospitals, but two-thirds of elective admissions involving surgery were treated in private hospitals (Australian Institute

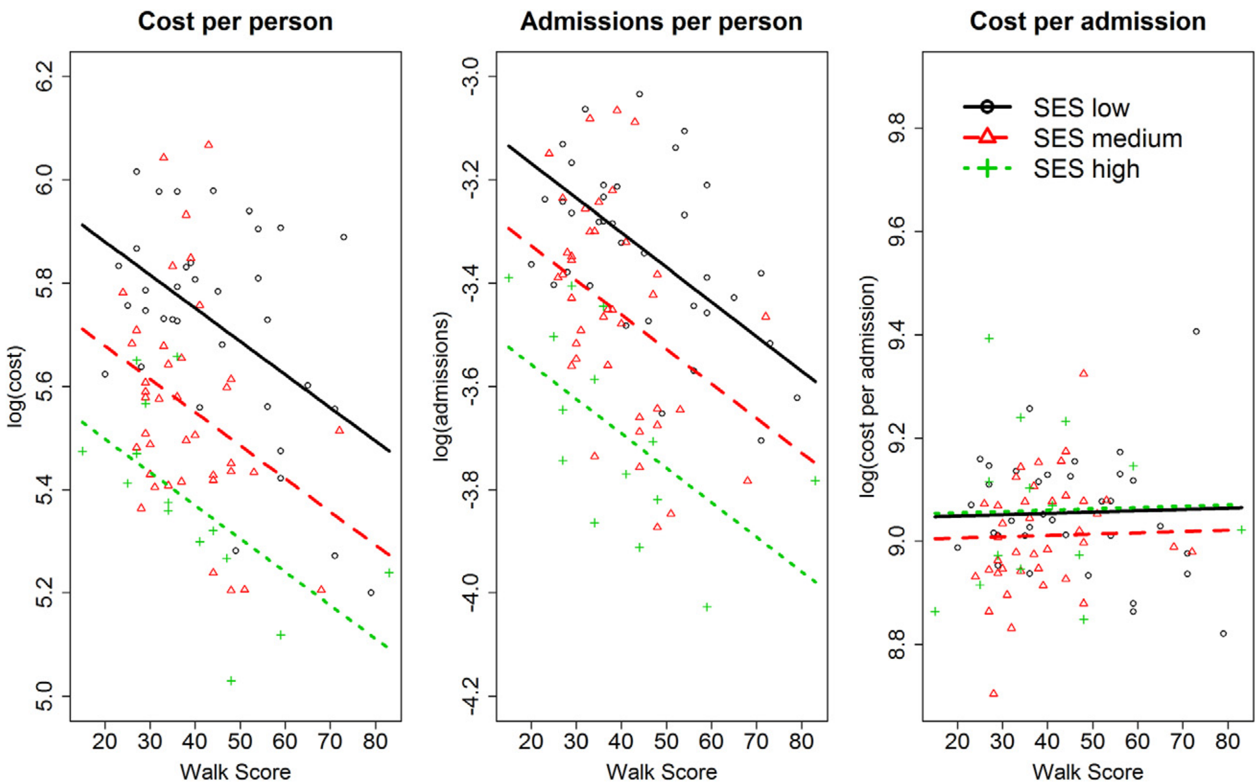

Fig. 1. Hospital treatment costs (logarithmic scale) vs. Walk Score®, by socioeconomic status (SES), 2011–2013 ACT admitted patient care database. Notes: 1. Raw data points and SES-adjusted linear regression lines; 2. Acute public hospital admissions in 88 ACT neighborhoods due to cancers, endocrine, nutritional and metabolic diseases, circulatory diseases and respiratory diseases.

of Health and Welfare, 2014a). Of all inpatients living in neighborhoods in the top SES quintile, 59% were treated in private hospitals, in contrast to 26% of patients in the bottom SES quintile (Australian Institute of Health and Welfare, 2014a). In the ACT, it is possible that a greater proportion of the omitted private hospital admissions were made by patients from the less walkable neighborhoods, which were somewhat of higher SES (Table 2). The statistical adjustment for SES partially alleviates the issue of omitting private hospital admissions in the analysis. However, residual associations between socioeconomic conditions, walkability and private admissions could still put a downward bias in our results, in particular driving the null association between neighborhood walkability and cost per admission as found here.

Another possible explanation for the lack of association between walkability and cost per admission is that the hospital cost estimates based on AR-DRG codes may have averaged out the variations across admissions. Further research analyzing related outcomes such as length of hospital stay and survival would be useful.

We found the associations between walkability and hospital outcomes did not vary across SES groups. Moreover, additional analyses (not shown) did not find statistically significant quadratic terms for Walk Score® in the regression models, thus not supporting a nonlinear relationship between Walk Score® and the outcomes. These results suggest that designing urban forms to enhance built environment features that are friendly to walking and physical activity may improve health outcomes and reduce hospital costs for a wide spectrum of people living in a variety of physical environments. Nonlinear threshold effects were previously detected for modes of travel at the highest population and employment densities (Frank and Pivo, 1994); however, the associations with the built environment were linear for the physical activity outcome in a cross-country study of 14 cities (Sallis et al., 2016), and did not vary across income levels for obesity in a Canadian study (Creatore et al., 2016). In our study, the number of neighborhoods with high Walk Score® values was small, especially for the high SES group (Table 2 and Fig. 1), which could limit the statistical power to detect variations.

In conclusion, we found lower hospital treatment costs in ACT neighborhoods with higher walkability. Compared with the least walkable neighborhoods, average hospital costs were 26–37% lower in the most walkable ones. A 20-unit increase in walkability was associated with ~12% reductions in hospital cost per person and admissions per person. Results here suggest the potential for designing more walkable environments to promote physically active living, improve population health and reduce health care costs. Future research would benefit from linkage of the hospital records with individual behavioral data (e.g., from sample surveys) to study and understand more fully the interrelationships between built environment, health behaviors and health outcomes.

Conflict of interest

The authors declare no conflict of interest.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at http://dx.doi.org/10.1016/j.ypmed.2017.02.008.

References

Australian Bureau of Statistics, 2011a. Australian Statistical Geography Standard (ASGS): Volume 1—Main Structure and Greater Capital City Statistical Areas.

Australian Bureau of Statistics, 2011b. Socio-Economic Indexes for Areas (SEIFA).

Australian Bureau of Statistics, 2015a. Australian Bureau of Statistics. 3101.0—Australian Demographic Statistics, Dec 2014. http://www.abs.gov.au/AUSSTATS/abs@.nsf/Lookup/3101.0Main+Features1Dec%202014?OpenDocument.

Australian Bureau of Statistics, 2015b. Australian Bureau of Statistics. 3235.0—Population by Age and Sex, Regions of Australia, 2013. http://www.abs.gov.au/AUSSTATS/abs@.nsf/Lookup/3235.0Main+Features12013?OpenDocument.

Australian Institute of Health and Welfare, 2014a. Admitted Patient Care 2012–13: Australian Hospital Statistics, Health Services Series No. 54. Cat. No. HSE 145. AIHW, Canberra.

Australian Institute of Health and Welfare, 2014b. Health Expenditure Australia 2012–13, Health and Welfare Expenditure Series No. 52. Cat. No. HWE 61. AIHW, Canberra.

Booth, F.W., Roberts, C.K., Laye, M.J., 2011. Lack of Exercise Is a Major Cause of Chronic Diseases, Comprehensive Physiology. John Wiley & Sons, Inc.

Carr, L.J., Dunsiger, S.I., Marcus, B.H., 2010. Walk Score as a global estimate of neighborhood walkability. Am. J. Prev. Med. 39, 460–463.

Carr, L.J., Dunsiger, S.I., Marcus, B.H., 2011. Validation of Walk Score for estimating access to walkable amenities. Br. J. Sports Med. 45, 1144–1148.

Chiu, M., Rezai, M.R., Maclagan, L.C., Austin, P.C., Shah, B.R., Redelmeier, D.A., Tu, J.V., 2016. Moving to a highly walkable neighborhood and incidence of hypertension: a propensity-score matched cohort study. Environ. Health Perspect. 124, 754–760.

Cole, R., Dunn, P., Hunter, I., Owen, N., Sugiyama, T., 2015. Walk Score and Australian adults' home-based walking for transport. Health Place 35, 60–65.

Committee on Physical Activity, Health, Transportation, and Land Use, Transportation Research Board, Institute of Medicine of the National Academies, 2005d. Does the Built Environment Influence Physical Activity?: Examining the Evidence, TRB Special Report 282. Transportation Research Board, Washington, D.C.

Cowie, C.T., Ding, D., Rolfe, M.I., Mayne, D.J., Jalaludin, B., Bauman, A., Morgan, G.G., 2016. Neighbourhood walkability, road density and socio-economic status in Sydney, Australia. Environ. Health 15, 58.

Creatore, M.I., Glazier, R.H., Moineddin, R., et al., 2016. Association of neighborhood walkability with change in overweight, obesity, and diabetes. JAMA 315, 2211–2220.

Cutler, D.M., Lleras-Muney, A., Vogl, T., 2008. Socioeconomic Status and Health: Dimensions and Mechanisms. National Bureau of Economic Research.

Duncan, D.T., Aldstadt, J., Whalen, J., Melly, S.J., Gortmaker, S.L., 2011. Validation of Walk Score for estimating neighborhood walkability: an analysis of four US metropolitan areas. Int. J. Environ. Res. Public Health 8, 4160–4179.

Duncan, D.T., Sharifi, M., Melly, S.J., Marshall, R., Sequist, T.D., Rifas-Shiman, S.L., Taveras, E.M., 2014. Characteristics of walkable built environments and BMI z-scores in children: evidence from a large electronic health record database. Environ. Health Perspect. 122, 1359–1365.

Ewing, R., Schmid, T., Killingsworth, R., Zlot, A., Raudenbush, S., 2003. Relationship between urban sprawl and physical activity, obesity, and morbidity. Am. J. Health Promot. 18, 47–57.

Frank, L.D., Pivo, G., 1994. Impacts of mixed use and density on utilization of three modes of travel: single-occupant vehicle, transit, and walking. Transp. Res. Rec. 1466, 44–52.

Gluckman, P., Hanson, M., 2006. Developmental Origins of Health and Disease. Cambridge University Press, Cambridge.

Independent Hospital Pricing Authority, 2014. National Hospital Cost Data Collection Australian Public Hospitals Cost Report 2011–2012, Round 16.

Independent Hospital Pricing Authority, 2015. National Hospital Cost Data Collection Australian Public Hospitals Cost Report 2012-2013, Round 17.

King, K.E., Clarke, P.J., 2015. A disadvantaged advantage in walkability: findings from socioeconomic and geographical analysis of national built environment data in the United States. Am. J. Epidemiol. 181, 17–25.

McCormack, G.R., Shiell, A., 2011. In search of causality: a systematic review of the relationship between the built environment and physical activity among adults. Int. J. Behav. Nutr. Phys. Act. 8, 125.

OECD, 2015. Health at a Glance 2015: OECD Indicators. OECD Publishing, Paris.

Renalds, A., Smith, T.H., Hale, P.J., 2010. A systematic review of built environment and health. Fam. Community Health 33, 68–78.

Saelens, B.E., Sallis, J.F., Frank, L.D., 2003. Environmental correlates of walking and cycling: findings from the transportation, urban design, and planning literatures. Ann. Behav. Med. 25, 80–91.

Sallis, J.F., Floyd, M.F., Rodríguez, D.A., Saelens, B.E., 2012. Role of built environments in physical activity, obesity, and cardiovascular disease. Circulation 125, 729–737.

Sallis, J.F., Cerin, E., Conway, T.L., Adams, M.A., Frank, L.D., Pratt, M., Salvo, D., Schipperijn, J., Smith, G., et al., 2016. Physical activity in relation to urban environments in 14 cities worldwide: a cross-sectional study. Lancet 387, 2207–2217.

Smith, J.P., 2007. The impact of socioeconomic status on health over the life-course. J. Hum. Resour. 42, 739–764.

Sriram, U., LaCroix, A.Z., Barrington, W.E., Corbie-Smith, G., Garcia, L., Going, S.B., LaMonte, M.J., Manson, J.E., Sealy-Jefferson, S., et al., 2016. Neighborhood walkability and adiposity in the Women's Health Initiative cohort. Am. J. Prev. Med. 16, 30101–30105.

Walk Score®, 2015. Walk Score® Walkability Index for Suburbs, Canberra, Australian Capital Territory. https://www.walkscore.com/AU-ACT/Canberra.

Wasfi, R.A., Dasgupta, K., Orpana, H., Ross, N.A., 2016. Neighborhood walkability and body mass index trajectories: longitudinal study of Canadians. Am. J. Public Health 106, 934–940.

World Health Organization, 2014. Global Status Report on Noncommunicable Diseases 2014. World Health Organization.