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The cost-effectiveness of installing sidewalks to increase levels of transport-walking and health

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ABSTRACT

Objective. This study investigated the cost-effectiveness of installing sidewalks to increase levels of transport-walking.

Methods. Secondary analysis using logistic regression established the association of sidewalks with transport-walking using two transport-walking thresholds of 150 and 60 min/week using Western Australian data (n = 1394) from 1995 to 2000. Minimum, moderate and maximum interventions were defined, associated respectively with one sidewalk, at least one sidewalk and sidewalks on both sides of the street. Costs, average and incremental cost-effectiveness ratios were calculated for each intervention and expressed as 'the cost per person who walks for transport for more than 150 min/week (60 min/week) after the installation of new sidewalks'. A sensitivity analysis examined the robustness of the incremental cost-effectiveness ratios to varying model inputs. Costs are in 2012 Australian dollars.

Results. A positive relationship was found between the presence of sidewalks and transport-walking for both transport-walking thresholds of 150 and 60 min/week. The minimum intervention was found to be the most cost-effective at $2330/person and $674/person for the 150 and 60 min/week transport-walking thresholds respectively. Increasing the proportion of people transport-walking and increasing population density by 50% improved the cost-effectiveness of installing side-walks to $346/person.

Conclusions. To increase levels of transport-walking, retrofitting streets with one sidewalk is most cost-effective.

Introduction

Physical inactivity accounts for 6.6% of the total burden of disease and injury in Australia and is a major risk factor to ill health (Begg et al., 2007). Interventions focusing on individual and social environmental factors related to physical activity have only had modest effects on behavioral change (Giles-Corti et al., 2005). Thus, emphasis has been placed on modifying the built environment as a more sustainable means of increasing population levels of physical activity and health (Committee on Physical Activity, 2005; Ewing, 2005; Giles-Corti et al., 2005). This reflects an ecological approach to behavior changes and acknowledges multiple levels of influence (Sallis and Owen, 2002).

The most common form of physical activity among adults is walking, with three 10 minute bouts of brisk walking daily sufficient to protect health (Giles-Corti and Donovan, 2003; Owen et al., 2004; National Physical Activity Guidelines, 2005). People can engage in transport-walking (i.e., walking to work or the shops) and recreational-walking (i.e., for exercise or enjoyment), with different types of walking associated with different environmental attributes (Owen et al., 2004).

Commonly reported locations for walking are in the streets followed by public open spaces (Giles-Corti and Donovan, 2003). Easily accessible for all population groups, streets and street networks are a major contributor to neighborhood walkability and are relatively permanent in their design and serve a variety of uses besides walking (Van Dyck et al., 2013; Ehrenfeucht and Loukaitou-Sideris, 2010). Defined by high population density, mixed land use, and recreational and business destinations, highly walkable neighborhoods are also characterized by good street connectivity. Street connectivity improves access to routes for which sidewalks are integral in providing a sense of safety and convenience by separating pedestrians from motor vehicle traffic as conceptualized in the model proposed by Sugiyama et al. (2012). As a route attribute in this model, sidewalks are expected to influence transport-walking directly, and, by interacting with other factors including street connectivity, esthetics, and safety, additional sidewalks may also influence transport-walking indirectly (Humpel et al., 2002; Saelens et al., 2003; Duncan et al., 2005).

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Despite limited budgets, fragmented governance, and other barriers affecting the design, provision and maintenance of sidewalks, many infrastructure projects focus on sidewalk provision for which research and economic evaluations are requisite for an efficient use of resources and for having practical relevance to policy making (Rush et al., 2004; Ehrenfeucht and Loukaitou-Sideris, 2010; Evenson et al., 2011). While a number of studies have investigated the association between the built environment and walking, few studies have incorporated cost-effectiveness analyses (McCormack et al., 2004, 2012; Wendel-Vos et al., 2007; Saelensminde, 2004; Wang et al., 2004; Boarnet et al., 2008; Guo and Gandavarapu, 2010).

Using a societal perspective, the aim of this study was to assess the cost-effectiveness of installing sidewalks to increase transport-walking.

Methods

Survey data

This study uses data from the Study of Environmental and Individual Determinants of Physical Activity I and II (SEID I and II) (Giles-Corti and Donovan, 2002, 2003; Pikora et al., 2006). The SEID I cross-sectional survey collected data on demographics, individual attitudes, social characteristics and physical activity behaviors for 1803 randomly selected healthy workers and home-makers aged 18–59 years, living in metropolitan Perth, Western Australia between October 1995 and March 1996 (Giles-Corti and Donovan, 2003). In 2000, the SEID II survey collected data on the physical and environmental characteristics of 1987 km of street segments located within a 400-meter radial buffer around 1678 residences of participants previously surveyed in SEID I. Street segments are defined as the section of road between two consecutive intersections, and the 400-meter radial buffer represents the distance a person can walk in 5 minutes (Pikora et al., 2006). Data from SEID I were linked to SEID II providing complete analytical data for 1394 respondents. Full discussion of study methods for SEID I and II can be found elsewhere (Giles-Corti and Donovan, 2002, 2003).

Analysis of sidewalk data and transport-walking

Logistic regression analysis was used to examine the relationship between sidewalks and transport-walking. Two dichotomous outcome variables were examined: the first, for participants achieving recommended levels of physical activity of 150 minutes or more of walking (i.e., five or more occasions of 30 minutes per week) (Giles-Corti and Donovan, 2003); the second, examined participants achieving 60 minutes per week or more of walking in recognition that many people in Perth, Western Australia meet physical activity requirements by combining a range of physical activities (Giles-Corti and Donovan, 2003; Bauman et al., 2003; Christian et al., 2011). For both thresholds we used minutes spent on transport-walking per week to define the dichotomous outcome variables. Increasing transport-walking, which is a form of active-transport, leads to improved health and reduced health care costs, mode shifts from using vehicles to walking resulting in improved air-quality, and improved community and social connectedness (Giles-Corti et al., 2010).

Let j represent the sidewalk condition. Three binary variables were defined respectively for each sidewalk condition: $j = 0$ for streets with no sidewalks; $j = 1$ for a sidewalk on one side of the street; and $j = 2$, when there are sidewalks on both sides of a participant's street.

The proportion of people transport-walking, p_j was calculated using the predicted value from the estimated logit regression after adjustment for demographic and built environment factors associated with transport-walking and according to each sidewalk condition, j. The adjustments were made using the median predicted value of each logit model respectively (Hosmer et al., 2013). Logistic regression analysis was conducted using SPSS (Version 15) and results are shown in Table 2.

The three sidewalk interventions

Three sidewalk interventions were proposed to evaluate the increase in transport-walking due to the installation of sidewalks.

Let k denote each intervention. The 'minimum' intervention, $k = 1$, involved building a new sidewalk along street-segments without sidewalks. The 'moderate' intervention, $k = 2$, involved building new sidewalks on the opposing side of the street for street-segments with a single pre-existing sidewalk, and building a new sidewalk along street-segments without sidewalks. The 'maximum' intervention, $k = 3$, involved building new sidewalks so that every street-segment contained sidewalks on both sides. The baseline scenario, or *status quo*, is defined by the existing sidewalk network.

The effectiveness of installing sidewalks

Let i represent each of the 1394 participants. w_i, is defined as the number of people who walk above the transport-walking threshold for each of the 1394 400-meter radial buffer zones and was calculated by the equation in Fig. 1. For each of the 400-meter radial buffer zones, the proportion of street segments f_{ij} corresponding to participant 'i' and sidewalk condition 'j' was multiplied with their corresponding estimated sidewalk effects $\hat{p}_j$ and summed together.

To calculate exposure to the sidewalk intervention, the resulting summation was multiplied by population density, N. N was estimated by converting the 400-meter radial buffer into a total measure of square kilometers and multiplying this figure by an estimate of the population density per square kilometer of residential area. Residential area was estimated using Geographical Information System (GIS) estimates using Western Australia Mesh Block Digital Boundaries in ESRI Shapefile Format from Australian Bureau of Statistics (ABS) and ESRI ArcGIS 10.0 software using population estimates from the ABS.

The effectiveness of the kth sidewalk intervention, $\overline{w}_k$, was found by averaging the number of people w_i who walked for transport for more than either 150 min/week or 60 min/week due to the addition of new sidewalks across the 1394 participants respectively.

The cost of installing sidewalks

A town planner was consulted to provide the cost per linear meter for installing concrete sidewalks, their expected lifetime and the cost of replacement (P. McEvoy, personal communication, January 2010). Costs associated with installing sidewalks for each intervention were calculated using estimates of the proportion of missing sidewalks derived from the SEID II data.

The cost of installing sidewalks was quoted at $70 (AUD 2010)/square meter for a concrete sidewalk with a width of 1.8 meters. This figure was indexed to 2012 values using the ABS Producer Price Index for Roads and Bridges which includes pricing information on concrete. The resulting value in AUD 2012 values was $137.30/linear meter. The average lifespan of a sidewalk was quoted as 15 years and the cost of replacement every 15 years was $205.95/linear meter which was 50% higher than the initial installation cost due to additional costs of removing and disposing of old sidewalks. The cost of installing sidewalks was initially defined for a period of 15 years.

The Equivalent Annual Cost (EAC) of installing sidewalks for 15 years using a discount rate of 5% was calculated to be $13.22/linear meter. This annuitized cost was multiplied by the aggregate length of newly installed sidewalks derived from the estimates for each 400-metre radial buffer zone. The corresponding costs for each intervention were averaged across all 1394 participants, and are shown in Table 3.

Average and incremental cost-effectiveness ratios

Average cost-effectiveness ratios (ACERs) were calculated by dividing the cost of each intervention by the effectiveness of each intervention.

The incremental cost-effectiveness ratios (ICERs) were calculated by dividing the difference in costs between interventions by the difference in effectiveness between interventions i.e. between the *status quo* and the minimum intervention; the moderate and minimum interventions; and the maximum and moderate interventions respectively.

ACERs and ICERs were calculated for each transport-walking threshold of 150 and 60 min/week respectively and are also shown in Table 3.

Sensitivity analysis

A sensitivity analysis was conducted to assess the robustness of the results to varying model inputs. This included altering the proportion of people transport-walking via the transport-walking thresholds of 150 and 60 min/week and decreasing population density by 50%, increasing the project lifetime to 30 years on the basis that concrete used for sidewalks lasts between 20 and 40 years (Rajani, 2002), and altering the discount rates to reflect those most commonly used in economic evaluations which better reflect the intervention costs and benefits across long time horizons (Smith and Gravelle, 2001; Johnston and Hope, 2012). Rates of 0%, 3% and 7% were included.

The original scenario utilized a discount rate of 5%, a project lifetime of 15 years, with population density estimated as 827 people, and was examined

$$w_i = N \times \sum_{j=0}^{2} (f_{ij} \times \hat{p}_j)$$

Where w_i ≡ Number of people who walk for transport for more than 150 minutes per week in the 400 metre buffer zone surrounding respondent i.

N ≡ Number of people living in the 400 metre buffer zone.

f_{ij} ≡ Proportion of segments with sidewalk conditions 'j' corresponding to respondent 'i'.

$\hat{p}_j$ ≡ Proportion of people who walk above the transport-walking threshold given the presence of sidewalk conditions 'j'.

j ≡ The sidewalk conditions, where j = 0 to 2. A value of zero corresponds with no sidewalks along a street segment; a value of one corresponds with the presence of only one sidewalk along a street segment; and a value of two corresponds with the presence of sidewalks on both sides of a street segment.

i ≡ The index corresponding to each respondent, where i=1 to 1394.

Fig. 1. Formula used to calculate the number of people in the 400-meter radial buffer zone who walk above the transport-walking threshold (Perth, Western Australia).

using both transport-walking thresholds of 150 and 60 min/week respectively. The cost estimates and sensitivity analysis were conducted using Microsoft Excel 2007.

Results

The sample characteristics of SEID I and II participants are shown in Table 1.

Table 1
Sample characteristics of the baseline data (Perth, Western Australia).

Characteristic	n (%)
Age group (years)	
18–29	355 (25.5)
30–39	394 (28.3)
40–49	386 (27.7)
50–59	259 (18.6)
Gender	
Male	436 (31.3)
Female	958 (68.7)
Education	
Sub-secondary	293 (21.0)
Secondary	406 (29.1)
Certificate/trade	307 (22.0)
Tertiary	388 (27.8)
Socioeconomic status[a]	
Disadvantaged	675 (48.4)
Advantaged	719 (51.6)
Sidewalks along resident's street	
None	488 (35.0)
One side of the street	482 (34.6)
Both sides of the street	424 (30.4)
Walked for transport	
Less than 60 min/week	1026 (73.6)
For 60 min/week or more	368 (26.4)
Less than 150 min/week	1248 (89.5)
For 150 min/week or more	146 (10.5)

[a] Area level socioeconomic disadvantage was based on the Australian Bureau of Statistic's Socio-Economic Index For Areas (SEIFA), which reflects aggregate levels of income, education and employment for a census collector's district.

Establishing the association between sidewalks and transport-walking

Table 2 shows results from the estimated logistic regressions evaluating the presence of sidewalks along street segments and transport-walking for both transport-walking thresholds of 150 and 60 min/week respectively.

The presence of one sidewalk along a participant's street was positively associated with transport-walking for both transport-walking thresholds, however did not reach statistical significance at a significance level of 0.05 ($p = 0.051$) (OR 1.623; 95% CI 1.000–2.641) for a transport-walking threshold of 150 min/week. The presence of sidewalks on both sides of a participant's street was positively and significantly associated with transport-walking for more than 150 min/week (OR 2.069; 95% CI 1.227–3.490).

For the second model based on the transport-walking threshold of 60 min/week, the presence of one sidewalk was positively and statistically significant (OR 2.037; CI 1.461–2.840), as was the presence of two sidewalks (OR 2.515; CI 1.227–3.490).

Table 2 also presents the estimates for the proportion of people, $\hat{p}_j$ for both transport-walking thresholds. For brevity, in the remainder of this paper, figures reported in brackets refer to estimates based on the second transport-walking threshold of 60 min/week unless otherwise specified. The proportion of people transport-walking for 150 min/week (60 min/week) in the presence of no sidewalks was estimated to be 0.086 (0.253), 0.132 (0.409) for streets with one sidewalk and 0.162 (0.460) for streets with two sidewalks.

The effectiveness of installing sidewalks

Estimates for the effectiveness, $\overline{w}_k$, for the k interventions are shown in Table 3.

The effectiveness for the maximum intervention was estimated to be 133 (380) people, which is 27 (66) more people than estimated under the *status quo* option. The moderate intervention resulted in 126 (368) people and the minimum intervention resulted in 117 (352)

Table 2
Logistic regression[a] results examining the relationship between sidewalk conditions and transport-walking (Perth, Western Australia).

j	Sidewalk conditions	Odds ratio [95% confidence interval]	p-Value	$\hat{p}_j$
Dependent variable: $y_i = 1$ when transport-walking ≥ 150 min for respondent i, 0 otherwise. i = 1 to 1394.				
0	No sidewalks along street[b]	Not applicable	Not applicable	0.086
1	One sidewalk along street	1.623 [1.000–2.641]	0.051	0.132
2	Sidewalks on both sides of street	2.069 [1.227–3.490]	0.006	0.162
Dependent variable: $y_i = 1$ when transport-walking ≥ 60 min for respondent i, 0 otherwise. i = 1 to 1394.				
0	No sidewalks along street[b]	Not applicable	Not applicable	0.253
1	One sidewalk along street	2.037 [1.461–2.840]	0.000	0.409
2	Sidewalks on both sides of street	2.515 [1.748–3.617]	0.000	0.460

[a] Adjustments using the median predicted value for each logit model above, were made for age, sex, presence of children under 18 years in the household, working outside of home, household income, education level, occupation, marital status, motor vehicle availability, significant others encouraging individual to be active, perceived behavioral control, and attitude towards exercise, post-boxes, and delis.
[b] This was the reference case used in the calculation of the odds ratios for the other sidewalk conditions.

(i.e. 20 (54) and 11 (38) more people respectively than estimated under the *status quo* option).

The cost of installing sidewalks

The minimum intervention was the least costly, estimated at $25,630 followed by $59,316 for the moderate intervention and $84,946 for the maximum intervention.

The average and incremental cost-effectiveness ratios

ACERs and ICERs were calculated for each intervention and expressed as 'the cost per person who walks for transport for more than 150 min (60 min) per week after the installation of new sidewalks'. ACER and ICER estimates for each intervention and each walking threshold are shown in Table 3. For the transport-walking threshold of 150 min/week (60 min/week), the minimum sidewalk intervention had the best ACER at $2330/person ($674/person), followed by the moderate intervention at $2966/person ($1098/person), and $3146/person ($1287/person) for the maximum intervention. The ICER for the 150 min (60 min/week) transport-walking threshold for the minimum intervention was $2330/person ($674/person), $3743/person ($2105/person) for the moderate intervention and $3661/person ($2136/person) for the maximum intervention. The ICER for the maximum intervention dominates the moderate intervention for the transport-walking threshold of 150 min/week but not for the transport-walking threshold of 60 min/week.

Sensitivity analysis

Tables 4 and 5 show the results of the sensitivity analysis. Increasing the population density by 50% halved the ICERs while decreasing the population density more than doubled the ICERs for each of the *k* interventions. Extending the project lifetime to 30 years leads to small increases in the ICERs, with the moderate intervention dominated by the maximum intervention for the 150 min/week transport-walking threshold but not for the 60 min/week transport-walking threshold. Altering the discount rate resulted in modest changes in the ICERs, although for all three discount rates, the moderate intervention is dominated by the maximum intervention for the 150 min/week transport-walking threshold. The overall cost-effectiveness analysis when using both transport-walking thresholds of 150 min/week and 60 min/week is not sensitive to changes in the discount rate or project lifetime but is sensitive to changes in population density.

Discussion

The minimum intervention produced the best ACERs and ICERs after adjusting for other factors related to transport-walking for both transport-walking thresholds and for all sensitivity analyses. Increasing population density by 50% leads to the best ACER and ICER associated

Table 3
Average and incremental cost-effectiveness ratios based on three sidewalk installation interventions (Perth, Western Australia).

Intervention	k (sidewalk intervention number)	Cost ($)	People walking[a] ($\overline{w}_k$, no. of persons on average who walk within a 400-meter radial buffer zone for the kth intervention)	Average effectiveness (no. of persons on average who walk above the *status quo* threshold)	ACER[b] ($ per person who move above the *status quo* threshold on average)	Incremental cost[c] ($)	Incremental effectiveness[d] (incremental no. of persons who move above the walking threshold)	ICER[e] (incremental $ per person who move above the walking threshold)
Transport-walking threshold of 150 min per week								
Status quo[f]		–	106	–	–	–	–	–
Minimum	1	25,630	117	11	2330	25,630	11	2330
Moderate	2	59,316	126	20	2966	33,686	9	3743
Maximum	3	84,946	133	27	3146	25,630	7	3661
Transport-walking threshold of 60 min per week								
Status quo[f]		–	314	–	–	–	–	–
Minimum	1	25,630	352	38	674	25,630	38	674
Moderate	2	59,316	368	54	1098	33,686	16	2105
Maximum	3	84,946	380	66	1287	25,630	12	2136

[a] Adjusted for age, sex, presence of children under 18 years in the household, working outside of home, household income, education level, occupation, marital status, country of birth, motor vehicle availability, socioeconomic status of the area of residence, significant others encouraging individual to be active, perceived behavioral control, and attitude towards exercise, and the presence of nearby railways, post-boxes, newsagents, bus stops, delis and shops.
[b] The average cost-effectiveness ratio.
[c] Calculated as the difference in cost between: the minimum and moderate; and moderate and maximum interventions.
[d] Calculated as the difference in benefits between: the minimum and moderate; and moderate and maximum interventions.
[e] The incremental cost-effectiveness ratio.
[f] The *status quo* represents the existing sidewalk infrastructure.

Table 4
Results of the sensitivity analysis for a transport-walking threshold of 150 min per week (Perth, Western Australia).

Intervention	Cost ($)	People walking[a] (no. of persons on average who walk within a 400-meter radial buffer zone according to each intervention)	Average effectiveness (no. of persons on average who walk above the *status quo* threshold)	ACER[b] ($ per person who move above the *status quo* threshold on average)	Incremental cost[c] ($)	Incremental effectiveness[d] (incremental no. of persons who move above the walking threshold)	ICER[e] (incremental $ per person who move above the walking threshold)
Density (discount rate = 5%; project lifetime = 15 years)							
50% decrease (N = 414)							
Status quo[f]	–	53	–	–	–	–	–
Minimum	25,630	59	6	4272	25,630	6	4272
Moderate	59,316	63	10	5932	33,686	4	8422
Maximum	84,946	67	14	6068	25,630	3	8543
50% increase (N = 1654)							
Status quo[f]	–	212	–	–	–	–	–
Minimum	25,630	234	22	1165	25,630	22	1165
Moderate	59,316	253	41	1447	33,686	19	1773
Maximum	84,946	267	55	1544	25,630	14	1831
Project lifetime (discount rate = 5%; density N = 827)							
30 years							
Status quo[f]	–	106	–	–	–	–	–
Minimum	29,198	117	11	2654	29,198	11	2654
Moderate	67,572	126	20	3379	38,375	9	4264
Maximum	96,770	133	27	3584	29,198	7	4171
Discount rate (density N = 827, project lifetime = 15 years)							
0%							
Status quo[f]	–	106	–	–	–	–	–
Minimum	17,735	117	11	1612	17,735	11	1612
Moderate	41,045	126	20	2052	23,310	9	2590
Maximum	58,781	133	27	2177	17,735	7	2534
3%							
Status quo[f]	–	106	–	–	–	–	–
Minimum	22,284	117	11	2026	22,284	11	2026
Moderate	51,573	126	20	2579	29,289	9	3254
Maximum	73,858	133	27	2735	22,284	7	3183
7%							
Status quo[f]	–	106	–	–	–	–	–
Minimum	29,209	117	11	2655	29,209	11	2655
Moderate	67,598	126	20	3380	38,389	9	4265
Maximum	96,807	133	27	3585	29,209	7	4173

[a] Adjusted for age, sex, presence of children under 18 years in the household, working outside of home, household income, education level, occupation, marital status, country of birth, motor vehicle availability, socioeconomic status of the area of residence, significant others encouraging individual to be active, perceived behavioral control, and attitude towards exercise, and the presence of nearby railways, post-boxes, newsagents, bus stops, delis and shops.
[b] The average cost-effectiveness ratio.
[c] Calculated as the difference in cost between: the minimum and moderate; and moderate and maximum interventions.
[d] Calculated as the difference in benefits between: the minimum and moderate; and moderate and maximum interventions.
[e] The incremental cost-effectiveness ratio.
[f] The *status quo* represents the existing sidewalk infrastructure.

with the minimum intervention at $1165/person ($346/person) for the transport-walking threshold of 150 min/week (60 min/week), highlighting the importance of density and the proportion of people walking for the cost-effectiveness of built environment interventions.

The finding that density is a key driver of the cost-effectiveness of installing sidewalks is important but not surprising. The more people present, the more cost-effective will be built environment interventions. Density is often cited as being important in conjunction with other attributes such as diversity of land use, destination accessibility, distance to transit, design and demand management — known as the 6 Ds from Ewing and Cervero (2010). Flexible design allows the built environment to respond to changes in density, which will drive changes in the diversity of land use. Density influences transport-walking because it underpins the presence of local destinations and transit access (Forsyth and Krizek, 2010; Forsyth and Hearst, 2008; Forsyth et al., 2007; Agrawal and Schimek, 2007; Giles-Corti et al., 2012), which have been found to be a major influence on transport-walking (Cervero and Duncan, 2003; Forsyth and Krizek, 2010; Sugiyama et al., 2012).

The minimum intervention may be sufficient for transport-walking, however given the modest costs of the more intensive interventions, it is a value judgment whether investing more is worthwhile given the competing uses of sidewalks that have not been evaluated here (Ehrenfeucht and Loukaitou-Sideris, 2010) and the difficulty and cost of retro-fitting the built environment to meet increasing density. In some cases the moderate intervention was dominated by the maximum intervention, implying that it is technically possible to find a weighted combination of the minimum and maximum interventions that would remain more cost-effective than the moderate intervention. In practice, this raises concerns of equity, where some areas receive one sidewalk according to the minimum intervention and other areas receive two sidewalks following from the maximum intervention. At the very least, it would be important to install two sidewalks in all areas with high pedestrian use that require greater accessibility such as retail zones and around schools, and only one sidewalk in low density, low traffic or low pedestrian use areas (Hooper et al., 2014; Boarnet et al., 2009).

These findings suggest that installing sidewalks – particularly on both sides of the streets near local destinations – would increase active transportation, particularly if combined with interventions to promote more walking (Forsyth and Krizek, 2010; Pucher et al., 2010). This would result in a reduction in passive transport modes such as car use and an increase in active transportation modes potentially leading to improved environmental, economic and health outcomes. Sidewalk interventions would be more cost-effective if neighborhoods were higher in household density as more people would be exposed to the

Table 5
Results of the sensitivity analysis for a transport-walking threshold of 60 min per week (Perth, Western Australia).

Intervention	Cost ($)	People walking[a] (no. of persons on average who walk within a 400-meter radial buffer zone according to each intervention)	Average effectiveness (no. of persons on average who walk above the *status quo* threshold)	ACER[b] ($ per person who move above the *status quo* threshold on average)	Incremental cost[c] ($)	Incremental effectiveness[d] (Incremental no. of persons who move above the walking threshold)	ICER[e] (incremental $ per person who move above the walking threshold)
Density (discount rate = 5%; project lifetime = 15 years)							
50% decrease (N = 414)							
Status quo[f]	–	157	–	–	–	–	–
Minimum	25,630	176	19	1349	1349	19	1349
Moderate	59,316	184	27	2197	2197	8	4211
Maximum	84,946	190	33	2574	2574	6	4272
50% increase (N = 1654)							
Status quo[f]	–	629	–	–	–	–	–
Minimum	25,630	703	74	346	25,630	74	346
Moderate	59,316	735	106	560	33,686	32	1053
Maximum	84,946	760	131	648	25,630	25	1025
Project lifetime (discount rate = 5%; density N = 827)							
30 years							
Status quo[f]	–	314	–	–	–	–	–
Minimum	29,198	352	38	768	29,198	38	768
Moderate	67,572	368	54	1260	38,375	16	2398
Maximum	96,770	380	66	1466	29,198	12	2433
Discount rate (density N = 827, project lifetime = 15 years)							
0%							
Status quo[f]	–	314	–	–	–	–	–
Minimum	17,735	352	38	467	17,735	38	467
Moderate	41,045	368	54	760	23,310	16	1457
Maximum	58,781	380	66	891	17,735	12	1478
3%							
Status quo[f]	–	314	–	–	–	–	–
Minimum	22,284	352	38	586	22,284	38	586
Moderate	51,573	368	54	955	29,289	16	1831
Maximum	73,858	380	66	1119	22,284	12	1857
7%							
Status quo[f]	–	314	–	–	–	–	–
Minimum	29,209	352	38	769	29,209	38	769
Moderate	67,598	368	54	1261	38,389	16	2399
Maximum	96,807	380	66	1467	29,209	12	2434

[a] Adjusted for age, sex, presence of children under 18 years in the household, working outside of home, household income, education level, occupation, marital status, country of birth, motor vehicle availability, socioeconomic status of the area of residence, significant others encouraging individual to be active, perceived behavioral control, and attitude towards exercise, and the presence of nearby railways, post-boxes, newsagents, bus stops, delis and shops.
[b] The average cost-effectiveness ratio.
[c] Calculated as the difference in cost between: the minimum and moderate; and moderate and maximum interventions.
[d] Calculated as the difference in benefits between: the minimum and moderate; and moderate and maximum interventions.
[e] The incremental cost-effectiveness ratio.
[f] The *status quo* represents the existing sidewalk infrastructure.

intervention. Furthermore, high density areas would facilitate more local walking as these areas are likely to have increased access to local destinations and transit. Dissemination of these findings to city-planners, policy- and decision-makers supports the incorporation and application of these research findings into policy and practice, which is paramount to designing healthy and flexible built environments supportive of positive health and wellbeing outcomes and behaviors (Litman, 2011; Boarnet et al., 2011a, 2011b; Duncan, 2010; Genter et al., 2008; Sinnett et al., 2011; Boesch et al., 2008).

Limitations and strengths

There appear to be few evaluations examining the cost-effectiveness of built environment interventions to increase levels of physical activity (Boarnet et al., 2008; Wang et al., 2004; Guo and Gandavarapu, 2010; Stokes et al., 2007). Two of these used ACERs to examine the cost-effectiveness of installing and maintaining a set of bicycle and pedestrian trails in Lincoln, Nebraska (Wang et al., 2004). These studies were limited due to the absence of clearly defined baseline data, although the issue of calculating a cost for the baseline remains a limitation in this paper. Saelensminde (2004) and Guo and Gandavarapu (2010) took a societal perspective in conducting a cost–benefit analysis of installing sidewalks and included a range of benefits that accrue from changes in physical activity resulting from improved infrastructure (Saelensminde, 2004; Guo and Gandavarapu, 2010). Important co-benefits of sidewalks such as improvements to pedestrian safety, environmental impacts, community connectedness and reductions in vehicle use and traffic incidents although not included here would further improved cost-effectiveness ratios. Additionally, other factors and barriers to walking including traffic volume, street connectivity, street types, lighting, safety, and access to destinations should be included in future studies (Pikora et al., 2006; Ehrenfeucht and Loukaitou-Sideris, 2010).

Our study, had a narrow focus on health outcomes, and transport-walking in particular, using two thresholds of 150 minutes and 60 minutes per week of transport-walking. The 150 minute threshold was based on physical activity recommendations known to optimize chronic disease outcomes, and the 60 minute threshold was based on previous findings that those who achieve recommended levels of physical activity often undertake a variety of physical activities (Giles-Corti and Donovan, 2003; Bauman et al., 2003; Christian et al., 2011). However, health benefits can be achieved from doing any amount of physical activity and future research could investigate alternative ways of defining, combining and measuring health benefits which arise from combining the many forms of physical activity rather than relying upon transport-walking alone. For example, the analysis here could be extended by examining the influence of sidewalks on recreational-walking, or by using total minutes of walking (McCormack et al., 2012). However, to date, inconsistent results have been found associating recreational-walking with the presence of sidewalks (Lee and Mouden, 2006; Giles-Corti and Donovan, 2002; McCormack et al., 2012). The decision to focus on transport-walking was driven by the need for specificity in built environment and physical activity models (Giles-Corti et al., 2005; Owen et al., 2004). Nevertheless, future research could examine the influence of built environment factors on these different types of walking using dose–response analyses. If successful, incorporating and combining these other forms of walking behaviors and definitions of health benefits would increase the cost-effectiveness of sidewalk and built environment interventions.

A common limitation of cross-sectional studies is the difficulty in establishing causality between transport-walking and sidewalk provision due to self-selection where those inclined to walk choose to live in neighborhoods where sidewalks are present. This study is no different. However, the evidence on the impact of self-selection is mixed (McCormack and Shiell, 2011). Some cross-sectional studies find that not controlling for self-selection appears to overstate the effect of the built environment on transit-walking and travel behavior (Cao, 2010; Cao et al., 2009; Cervero, 2007; Zhou and Kockelman, 2008), while other cross-sectional studies find an understated effect (Pinjari et al., 2008). Importantly, one longitudinal study found a null effect (Giles-Corti et al., 2013). Hence, our failure to account for self-selection, may or may not be an issue as other reviews find that the relationship between the built environment and travel behavior exists despite self-selection (Cao et al., 2009; McCormack and Shiell, 2011; Van Dyck et al., 2013). However, the existence and magnitude of any attenuation caused by self-selection on the relationship between the built environment and travel behavior should continue to be evaluated in future research using longitudinal study designs and quasi-experiments (Mokhtarian and Cao, 2008; Cao, 2010; Cao et al., 2009; McCormack and Shiell, 2011).

This study may lack external validity to populations living outside of metropolitan Perth where effectiveness and costs of installing sidewalks may vary for populations living in other localities with differing built environment, individual and social characteristics. Moreover, this study was limited in that many of the model inputs, such as population density and the proportion of people walking are dynamic but were treated as static quantities. Finally, this study used self-reported total minutes of transport-walking associated with a participant's residential location and did not account for walking and sidewalk infrastructure in other locations such as in the working environment of study participants. Despite these limitations, this is a an important line of enquiry and future studies could: incorporate other aspects of the built environment; locations and types of physical activity; consider co-benefits across multiple sectors; and examine the impact on other subgroups such as children, disabled people, and older adults who have specific built environment needs related strongly to the presence of quality sidewalks; and use more comparable outcome measures such as quality-adjusted life years (QALYs) (Boarnet et al., 2005; Sallis and Kerr, 2006; Grant et al., 2012; Gallimore et al., 2011; Wilson et al., 2012).

Conclusions

The results of this study suggest that to increase levels of transport-walking for residents of low density cities such as Perth, Western Australia, retrofitting cities by installing at least one sidewalk on all streets is more cost-effective than installing sidewalks on both sides of each street. However, all sidewalk interventions represent a good investment given the modest ICERs estimated in this study and particularly as the likelihood of people walking increases with accessibility and quantity of sidewalks. Hence, at the very least, two sidewalks should be installed in areas around local destinations. Population density and the proportion of people walking have the greatest impact on the cost-effectiveness of installing sidewalks. Increasing both of these would improve the cost-effectiveness of sidewalk interventions.

The results of this study should be interpreted with caution due to the limitations identified. However, further research is warranted to more fully address the cost-effectiveness of built environment interventions to reduce the burden of disease associated with physical inactivity.

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Conflict of interest statement

The authors declare that there are no conflicts of interest.

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