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Cost effectiveness of investing in sidewalks as a means of increasing physical activity: a RESIDE modelling study

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ABSTRACT

Background

Studies consistently find that supportive neighbourhood built environments increase physical activity by encouraging walking. However, evidence on the cost-effectiveness of investing in built environment interventions as a means of promoting physical activity is lacking. In this study we assess the cost-effectiveness of increasing sidewalk availability as one means of encouraging walking.

Methods

Using data from the RESIDE study in Perth, Australia, we modelled the cost impact and health outcomes of installing additional sidewalks in established neighbourhoods. Estimates of the relationship between sidewalk availability and walking were taken from a previous study. Multi-state life table models were used to estimate the health outcomes associated with changes in walking frequency and duration. Sensitivity analyses were used to explore the impact of variations in population density, discount rates, sidewalk costs and the inclusion of unrelated health care costs in added life years.

Results

Installing and maintaining an additional 10 km of sidewalk in an average neighbourhood with 19,000 residents was estimated to cost A$4.2 million over 30 years and avert 24 DALYs over the lifetime of the current population. The incremental cost-effectiveness ratio was A$176,000/DALY. However, sensitivity results indicated that increasing population densities improves cost-effectiveness.

Conclusions

In low density cities such as in Australia, installing sidewalks in established neighbourhoods as a single intervention is unlikely to cost- effectively improve health. Sidewalks must be considered alongside other complementary elements of walkability, such as density, land use mix and street connectivity. Population density is particularly important because at higher densities, more residents are exposed and this improves the cost-effectiveness. Health gain is one of many benefits of enhancing neighbourhood walkability and future studies might consider a more comprehensive assessment of its social value.

Article summary

Strengths and limitation of this study

- The well-established multi-state multi-cohort life table approach was used to estimate the potential health benefits of investing in sidewalks to encourage physical activity
- Health outcomes considered included reductions in mortality and morbidity, and health-adjusted life years gained
- Findings were adjusted for self-selection effects
- Effect estimates for the association of sidewalk availability with physical activity are potentially subject to recall bias
- Only one interventions is considered in this study, however, to impact on walking and health, there is a need for integrated built environment interventions.

INTRODUCTION

Physical inactivity is an important risk factor for many chronic diseases including diabetes, cardiovascular disease and some types of cancer [1]. In Australia, physical inactivity ranks eighth as a risk factor for death and ninth as a risk factor for disability adjusted life-years (DALYs) [2]. Yet despite the known benefits, too few adults in Australia [3] and elsewhere [4, 5] participate in levels of physical activity optimal for health. Even small increases in physical activity reduce the risk of chronic disease and provide health benefit [6]. Creating supportive built environments can cause positive shifts in population levels of physical activity and significantly reduce the burden of disease and related health care spending [7].

There is increasing attention for the role of the built environment, and in particular neighbourhood urban form, in either facilitating or inhibiting physical activity [8]. Several neighbourhood built environment characteristics, including the mix and diversity of land uses and destinations, population or residential density, and street and pedestrian connectivity, are consistently found to be positively associated with physical activity, and in particular walking [9-12]. Other built environment attributes are also important for supporting walking such as access to transit, availability and quality of sidewalks/ footpaths, street appeal or aesthetics, and personal and traffic safety [10, 13-17]. These built environment characteristics collectively contribute to the ‘walkability’ of a neighbourhood, which is found to be positively associated with walking and other physical activity behaviours [9, 18]. Creating ‘walkable’ neighbourhoods would also produce co-benefits and meet other social objectives such as sustainable transportation, reduction in air pollution and increased social connectivity [19, 20]. If these health and social benefits could be realised at a reasonable cost then environmental interventions that improve the walkability of residential neighbourhoods may be a cost-effective means of promoting health and well-being.

There are few economic evaluations of environmental interventions and most of the available evidence relates to designated walking trails or transport-related infrastructure, such as cycle paths [21-23]. However, none of these studies adjusted effect estimates for bias introduced by residential self-selection [24] and only one [23] controls for other built environment characteristics. A systematic review found the median benefit to cost ratio to be 5:1, suggesting that every $1 invested in transport-related infrastructure generates benefits worth $5 (including the financial value of reduced demand on the health care system) [25]. Despite this important finding, the authors hesitated from drawing policy-relevant conclusions citing a lack of transparency and variation in the methods employed in studies as a cause for concern. The need to account more accurately for the effect of built environment measures on physical activity was highlighted in a recent systematic review of transport economic evaluations [26].

Others have undertaken economic evaluations of urban form in relation to walking and health. Boarnet, Greenwald and McMillan [27] used regression analysis on travel survey data from Portland, Oregon, to quantify the impact of built environmental features on distance walked. Walking was translated into lives saved, with each life valued in dollar terms using published estimates of the value of a statistical life ranging from US$2 million to US$6.1 million per life saved. Their analysis suggested that two lives would be saved per year for every 1000 people exposed to a more walkable environment. While this finding is promising, missing from the work was any attempt to quantify the cost of the environmental interventions that might help realise these benefits.

Whilst recognising the need to evaluate the complementary effects of each component of a neighbourhood that collectively enhances walkability, this paper begins this important work by focussing on one aspect, namely the presence of sidewalks. Building sidewalks is something that planners could require in all new housing, and which could be retrofitted in established neighbourhoods.

This study considers the cost-effectiveness of spending to extend the length of sidewalks in a neighbourhood to increase levels of walking and improve health. The effect estimates applied in this modelling exercise were adjusted for other built environment features (implicitly holding all other features of the neighbourhood environment constant) and for residential self-selection, which allows for the evaluation of the independent and unbiased effect of increasing sidewalks.

METHODS

Overview

This economic evaluation involved four stages: 1) estimate the effect of sidewalks on walking; 2) translate the expected increase in walking into a reduction in DALYs lost and health care costs; 3) estimate the costs of extending sidewalk length; and 4) derive estimate of economic value of investing in sidewalks to increase physical activity in terms of the cost per DALY averted. A health sector perspective was used in which the costs of sidewalks (as a health-promoting intervention) were included. An intervention of

30 years duration was assumed, a lifetime time horizon was applied, and costs and benefits were discounted at 3% to 2010 values.

Estimate of effect of sidewalks on walking

RESIDE data

Data for this stage of the evaluation were drawn from the RESIDential Environments Study (RESIDE) in Perth, Western Australia. RESIDE is a longitudinal study examining the relationship between urban design and a number of social outcomes including physical activity. The opportunity for the RESIDE study arose when, in 1998, the Western Australia state government introduced new planning guidelines (the Liveable Neighbourhood Guidelines) incorporating ‘New Urbanist’ principles. The RESIDE study followed people relocating to new houses being built in one of 74 new housing developments, some of which were designed according to the Liveable Neighbourhoods guidelines. Information on the RESIDE project is detailed elsewhere [28]. The RESIDE dataset contains information on 1,813 people of whom 59% were female, 81% were married or in de facto relationships, 67% have children living at home, 22% were university educated, and 53% were either overweight or obese (average BMI was 26.05) [28].

Model estimates

We used estimates of the relationship between sidewalk length and walking behaviour from the RESIDE cross-sectional baseline survey in this economic evaluation [28]. Data included self-reported neighbourhood-based transportation and recreational walking, socio-demographic characteristics, attitudes towards walking, and variables related to residential self-selection. Neighbourhood-based transportation and recreational walking had been measured using the Neighbourhood Physical Activity Questionnaire, which provides reliable estimates of the proportion of people who walk and the average minutes spent walking in a usual week, within and outside the neighbourhood [29]. This degree of specificity has proved useful in linking walking for different purposes (transport, leisure) with particular neighbourhood attributes. The built environment within 1.6km around participants' homes had been assessed using Geographical Information Systems and satellite imagery to derive objectively-determined measures of neighbourhood walkability (i.e., land use mix, residential density, and street connectivity) [30] and sidewalk length. A Heckman two-staged regression model had then been used to estimate the association between sidewalk length in the neighbourhood and (a) the proportion of people walking for transport or leisure in the neighbourhood, and (b) the total minutes spent walking in the neighbourhood in a usual week among those who reported any walking [31]. McCormack et al. [31] provide a detailed description of the method and results of the Heckman modelling, but in brief, the decision about whether or not to walk was estimated using a multivariate Probit regression followed by a sample selection-bias corrected ordinary least squares regression for minutes spent walking. Estimates of the association between sidewalk length and neighbourhood walking were then adjusted for differences in walkability, attitude towards walking, neighbourhood preferences (i.e., access to services, recreation, and schools, pedestrian and cycling friendly streets, and housing variety), age, gender, and education [31]. McCormack et al. [31] included neighborhood preferences in the probit and linear regression models to adjust for the effect of residential self-selection on walking.

Modelling Health Outcomes and Health Care Costs

To translate the Heckman model estimates of walking as a function of sidewalk length into an estimate of health outcomes and health care costs avoided we used the mathematical model developed for the Assessing Cost Effectiveness in Prevention (ACE-Prevention) project [32]. Baseline health and cost parameters were updated from 2003 to 2010. See supplementary material for further detail.

All health outcomes and costs were measured over the lifetime of the 2010 Australian population. Health outcomes were evaluated in disability-adjusted life years (DALYs) as recommended by the World Health Organization (WHO) [33]. DALYs were preferred over quality-adjusted life years (QALYs) as DALYs are calculated using a standard set of weights across diseases as opposed to QALYs which are based on overall health states without specific weights for diseases [34]. A macro simulation approach was used to calculate changes in DALYs arising from expected changes in physical activity levels following a hypothetical increase in sidewalk length by applying a proportional multi-state multi-cohort life table model [35] (Supplementary Material).

Although the same disability weights are used, the method applied here for the estimation of DALYs differs from the WHO Global Burden of Disease (GBD) approach [36]. Notably, in the GBD method the change in years of life lost component of the DALY is calculated using hypothetical low mortality rates whereas in our model we use current Australian mortality rates.

Intervention Costs

The intervention was defined as spending to increase the length of sidewalks by 10km in each 1.6 km road network buffer surrounding a participant's home and maintaining this for 30 years. The cost of installing a standard sidewalk was determined to be A$172 (2012/2013) per square metre based on estimates of actual sidewalk replacement costs obtained from council documents [37-39]. Previous research used a value of A$70 per linear meter for a sidewalk of 1.8m in width [16], however, more recent evidence suggests that the price per square meter is likely to be higher [37-39]. The initial capital cost and periodic maintenance costs were included, assuming sidewalk replacement after 15 years.

Exposure

More people than just the survey participants will benefit from the investment in sidewalks, and so we also need to take into account residential density to compute the number of people 'exposed' to the intervention. Planning guidelines for Perth from 2003 suggest an average residential density of 9 dwellings/hectare in low density areas [40]. Assuming an average of 2.55 adults per dwelling, this yields an estimate of 19,000 potential beneficiaries within a 1.6km circular area. We use this figure in our baseline estimate and revisit the assumption in our sensitivity analysis and discussion.

Intervention Cost-Effectiveness

An incremental cost-effectiveness ratio (ICER) is evaluated for the intervention by comparing model outcomes given current levels of physical activity with those that would be expected following an increase in the length of sidewalks in each neighbourhood. The net costs of the intervention are the costs of installing and maintaining the sidewalks plus the net effect that changes in health have on health care costs in future. Improved health reduces costs because of the reduction in diseases related to physical inactivity, but it also means that new health care costs may be incurred by people who now go on to develop unrelated conditions in their added years of life.

Ninety-five percent uncertainty intervals were determined for all outcome measures by Monte Carlo simulation (2,000 iterations), using the Excel add-in tool Ersatz (Epigear, Version 1.01). Uncertainty distributions around input parameters are described in Table 1. The results of the Monte Carlo analysis were then used to determine the probability of intervention cost-effectiveness against a cost-effectiveness threshold of A$60,000 per DALY [41, 42].

Table 1. Uncertainty input parameters

Parameter	Mean (SD)	Distribution	Source
Proportion doing any walking	62.40% (19.86%)	Beta	[31]
Extra walkers per additional 10km sidewalk	0.66% (9.68%)	Beta	[31]
Average minutes walked per walker	151.10 (123.15)	Lognormal	[31]
Extra minutes walked per 10km sidewalk	5.26 (2.93)	Lognormal	[31]
Disease cost offset	See supplementary material table 1	Uniform	Australian Institute of Health and Welfare Impacts Study 2001. Maximum/minimum assumed at ±25% of mean value
Relative risks of diseases	See supplementary material table 2	Normal (ln RR)	Physical activity [1] and Diabetes risks [43]

In addition, we vary the cost of sidewalk construction and maintenance, the residential density in the neighbourhood where the new sidewalks are located, and the discount rate in a series of one- and two-way sensitivity analyses. We also combine the cost of sidewalks with residential density to find the most cost-effective mix. All scenarios including the baseline are presented in Table 2.

Table 2. Evaluated scenarios

Scenarios	**Cost sidewalk per square meter (A$/m^2)**	**Residential density: dwelling per ha (number of adults*)**	**Discount rate per annum costs and health (%)**	**Other health care costs in added life years**
Baseline	166	9 (19,000)	3	No
Low cost sidewalk	136	9 (19,000)	3	No
High cost sidewalk	227	9 (19,000)	3	No
Low density	166	20 (41,000)	3	No
Medium density	166	30 (62,000)	3	No
High density	166	60 (123,000)	3	No
Low density/ Low cost sidewalk	136	20 (41,000)	3	No
Low density/ High cost sidewalk	227	20 (41,000)	3	No
Medium density/ Low cost sidewalk	136	30 (62,000)	3	No
Medium density/ High cost sidewalk	227	30 (62,000)	3	No
High density/ Low cost sidewalk	136	60 (123,000)	3	No
High density/ High cost sidewalk	227	60 (123,000)	3	No
Discount health 0% and costs 0%	166	9 (19,000)	0	No
Discount health 1% and costs 3%	166	9 (19,000)	3/1	No
Discount health 5% and costs 5%	166	9 (19,000)	5	No
Health care costs prolonged life excluded	166	9 (19,000)	3	Yes

*1.6 km road network buffer

RESULTS

Incremental Cost-Effectiveness

In the baseline scenario, the cost of installing and maintaining an extra 10 km of sidewalks is $4.1 million per neighbourhood. This investment is expected to avert 24 DALYs over the life span of the neighbourhood adult population (95% uncertainty interval (UI) 20 to 28) (Table 3, Baseline). After taking into account the net effect on health care costs the total cost increases to $4.2 million. The incremental cost-effectiveness ratio (ICER) is A$176,000 per DALY averted (95% UI A$148,000 to A$203,000), which lies well above the A$60,000/DALY threshold. Under the baseline scenario assumptions, there was 0% probability of this intervention being under A$60,000 per DALY (Table 4 and Figure 2).

Table 3.Cost Effectiveness Results

Scenarios	DALYs	Intervention cost[b] (A$)	Health care cost offsets[a] (A$)	Costs prolonged life (A$)	Net Cost (A$)	ICER (A$)
Baseline	24 (20 , 28)	4,077,694	-232,232	313,910	4,159,373	175,782
			(-185,343 , -288,222)	(264,636 , 374,670)	(4,134,899 , 4,186,344)	(147,983 , 203,463)
Low cost sidewalk	24 (20 , 28)	3,340,761	-232,232	313,910	3,422,440	144,635
			(-185,343 , -288,222)	(264,636 , 374,670)	(3,397,967 , 3,449,411)	(121,911 , 167,330)
High cost sidewalk	24 (20 , 28)	5,576,124	-232,232	313,910	5,657,802	239,115
			(-185,343 , -288,222)	(264,636 , 374,670)	(5,633,329 , 5,684,774)	(201,101 , 276,963)
Low density	51 (44 , 61)	4,077,694	-501,132	677,386	4,253,948	83,303
			(-399,951 , -621,953)	(571,056 , 808,499)	(4,201,137 , 4,312,149)	(70,416 , 96,162)
Medium density	78 (67 , 92)	4,077,694	-757,809	1,024,339	4,344,224	56,251
			(-604,803 , -940,514)	(863,548 , 1,222,608)	(4,264,364 , 4,432,236)	(47,635 , 64,908)
High density	154 (132 , 182)	4,077,694	-1,503,396	2,032,157	4,606,455	30,057
			(-1,199,852 , -1,865,858)	(1,713,168 , 2,425,497)	(4,448,024 , 4,781,059)	(25,527 , 34,652)
Low density/ Low cost sidewalk	51 (44 , 61)	3,340,761	-501,132	677,386	3,517,015	68,869
			(-399,951 , -621,953)	(571,056 , 808,499)	(3,464,205 , 3,575,216)	(58,276 , 79,413)
Low density/ High cost sidewalk	51 (44 , 61)	5,576,124	-501,132	677,386	5,752,378	112,652
			(-399,951 , -621,953)	(571,056 , 808,499)	(5,699,567 , 5,810,579)	(95,054 , 130,236)
Medium density/ Low cost sidewalk	78 (67 , 92)	3,340,761	-757,809	1,024,339	3,607,291	46,706
			(-604,803 , -940,514)	(863,548 , 1,222,608)	(3,527,432 , 3,695,303)	(39,604 , 53,933)
Medium density/ High cost sidewalk	78 (67 , 92)	5,576,124	-757,809	1,024,339	5,842,654	75,659
			(-604,803 , -940,514)	(863,548 , 1,222,608)	(5,762,794 , 5,930,665)	(63,987 , 87,309)
High density/ Low cost sidewalk	154 (132 , 182)	3,340,761	-1,503,396	2,032,157	3,869,523	25,246
			(-1,199,852 , -1,865,858)	(1,713,168 , 2,425,497)	(3,711,091 , 4,044,126)	(21,468 , 29,078)

High density/ High cost sidewalk	154 (132 , 182)	5,576,124	-1,503,396 (-1,199,852 , -1,865,858)	2,032,157 (1,713,168 , 2,425,497)	6,104,885 (5,946,453 , 6,279,489)	39,840 (33,798 , 45,955)
Discount health 0% and costs 0%	57 (49 , 67)	4,980,000	-451,438 (-360,947 , -559,008)	815,905 (691,928 , 969,496)	5,344,467 (5,279,735 , 5,422,494)	94,735 (80,509 , 108,668)
Discount health 1% and costs 3%	42 (36 to 49)	4,077,694	-231,952 (-186,346, -284,915)	580,915 (495,475 , 683,747)	4,426,658 (4,373,856, 4,489,457)	106,881 (92,107 , 122,033)
Discount health 5% and costs 5%	15 (12 , 17)	3,666,193	-159,890 (-127,587 , -198,580)	182,938 (153,130 , 219,227)	3,689,241 (3,673,755 , 3,706,601)	254,664 (213,699 , 295,717)
Health care costs prolonged life excluded	24 (20 , 28)	4,077,694	-232,232 (-185,343 , -288,222)	313,910 (264,636 , 374,670)	3,845,462 (3,789,472 , 3,892,351)	162,609 (134,756 , 190,513)

[a] Negative costs indicate savings.

[b] No uncertainty for intervention costs was assumed.

Table 4. Probability of being under A$60,000 per DALY threshold

Scenario	Probability
Baseline	0%
Low cost sidewalk	0%
High cost sidewalk	0%
Low density	0%
Medium density	79%
High density	100%
Low density/Low cost sidewalk	5%
Low density/High cost sidewalk	0%
Medium density/Low cost sidewalk	100%
Medium density/High cost sidewalk	0%
High density/Low cost sidewalk	100%
High density/High cost sidewalk	100%
Discount health 0% and costs 0%	0%
Discount health 1% and costs 3%	0%
Discount health 5% and costs 5%	0%
Health care costs prolonged life excluded	0%

************************(Insert Figure 1 about here) ***********************

************************(Insert Figure 2 about here) ***********************

Sensitivity Results

The results are extremely sensitive to some of the assumptions made in the analysis, especially in respect to changes in residential density, which materially affects the number of people benefiting from the intervention (Table 4). High residential density, or medium density if the cost of installing sidewalks is low, both generate ICERs consistently below the A$60,000 per DALY benchmark (Table 4 and Figure 2). For the medium density scenario, the probability of being under this threshold was 79%.

DISCUSSION

Principal findings

While sidewalks are important in supporting walking, these results show that investing in increasing the length of sidewalks in a neighbourhood, independent of other modifications to create a more walkable neighbourhood, is unlikely to be a cost-effective method of improving health at the existing (low) levels of residential density in Perth. That is to say, other means of increasing physical activity such as GP ‘prescriptions’ for physical activity, social marketing campaigns and supported use of pedometers generate health benefits at lower net cost [32].

The analysis is limited to the outcomes associated with the most important diseases related to physical inactivity. Other health benefits and broader social benefits such as those related to less reliance on motor vehicles, or to any increase in sense of community that results from seeing more of one’s neighbours on the street, have been ignored [44, 45]. Thus, one cannot conclude from this work that investing in extending sidewalks is not cost-effective per se. Health gain is, to some extent, an externality or fortunate by-product of decisions that make neighbourhoods more walkable and ultimately more liveable. A more complete evaluation would reflect the value of all outcomes of importance.

The model estimates used for the association between sidewalks and walking also have limitations [31]. The estimates of walking, while specific to the neighbourhood context, were self-reported and therefore prone to recall and memory errors. Further, not all walking trips, either for transportation or recreation, are within the neighbourhood. Our context-specific approach, which matched neighbourhood sidewalks with neighbourhood walking, is a strength of this study. However, this approach may underestimate the total influence of sidewalks on walking, as some walking that originated from within the neighbourhood may have also included some walking outside the neighbourhood. Furthermore, sidewalk provision may also support more vigorous-intensity physical activities such as jogging and running, which can provide health benefits over and above those provided by more moderate-intensity physical activity such as walking [46, 47].

Sidewalk within the broader context

Investment in sidewalks might have a bigger marginal impact on physical activity and produce more health benefits if it were accompanied by complementary efforts to improve other aspects of walkability such as the number and mix of destinations that people can walk to (land use mix), street connectivity and the aesthetic quality of the physical environment. People not only need something to walk on, but also somewhere to walk to. Such a comprehensive approach is likely to have both additive and synergistic benefits as each component of walkability complements the others. It might be also necessary to have other health promotion strategies in place, in addition to the built environment changes, to maximise the impact of this investment on physical activity.

Notably, our results show strongly the importance of residential density. In higher density neighbourhoods the fixed costs of neighbourhood improvements are spread over more people leading to greater overall benefit, which improves cost-effectiveness. By international standards, density in Australia is very low. While one of the aims of the Western Australian Liveable Neighbourhood Guidelines is to increase density, density remained low [40], there is still a demand for large houses on large blocks in Australian cities, with little appetite to mandate higher densities. Nevertheless, policies such as the Liveable Neighbourhood Guidelines are influential in changing practice, and average densities of up to 19 houses per hectare are now being observed in green-field developments in Perth [48]. Although that is an improvement over 9 houses per hectare, at 19 houses per hectare the population density is expected to be approximately 40,000 people in a neighbourhood, which implies zero probability for the installation of sidewalks to be cost-effective from the perspective of this study (Table 2).

Policy implications

Retro-fitting established neighbourhoods to improve walkability is challenging as it involves changing existing infrastructure and housing stock. Such change is often resisted by residential and government bodies and communities. Infrastructure improvements likely to improve health will require a comprehensive long-term strategy involving integrated planning of infrastructure, housing, transport, land use and urban design [49]. To this end, the development industry has an important role to play in providing leadership in developing new models for homes in green-field sites that meet the need for more compact developments for a healthier and more sustainable future. Similarly, planning regulations relating to shared occupancy, infill development and housing renewal should aim to increase higher density housing supply, resulting in greater use of existing infrastructure such as sidewalks, transportation, public open space and utilities.

The challenges of retro-fitting existing neighbourhoods and our findings here on the significance of walking draw attention to the need to design pedestrian-friendly neighbourhoods from the outset to facilitate active transport and recreational walking.

CONCLUSION

This work adds to a growing evidence base examining the cost-effectiveness of intervening in the built environment as a means of increasing physical activity and improving health and social outcomes. It points to the potential offered by neighbourhood redevelopment yet highlights the need for a comprehensive strategy that seeks both to improve all elements of walkability including land use mix and street connectivity. In particular it highlights the importance of residential density as a mechanism through which the cost effectiveness of infrastructure is affected because the higher the density, the lower the fixed cost per person who has access to that infrastructure.

COMPETING INTEREST

None to declare.

AUTHORS' CONTRIBUTIONS

A. Shiell, B. Giles-Corti, J.L. Veerman and G. McCormack developed the initial design of the study, oversaw and supervised the empirical work and contributed in drafting the first manuscript. L. Gunn and B. Zapata-Diomedi revised and amended the first manuscript and all authors revised the final version of the paper. L. Cobiac set up the original economic model and B. Zapata-Diomedi revised and updated the economic model with demographic, cost and epidemiologic data, ran the models and wrote the results. B. Zapata-Diomedi drafted the abstract and appendix and J.L. Veerman revised them. L. Gunn, G. McCormack and A. Shiell provided the interventions costs. A.M. Mantilla-Herrera produced the epidemiological estimates. All authors contributed to and commented on the final version of the manuscript.

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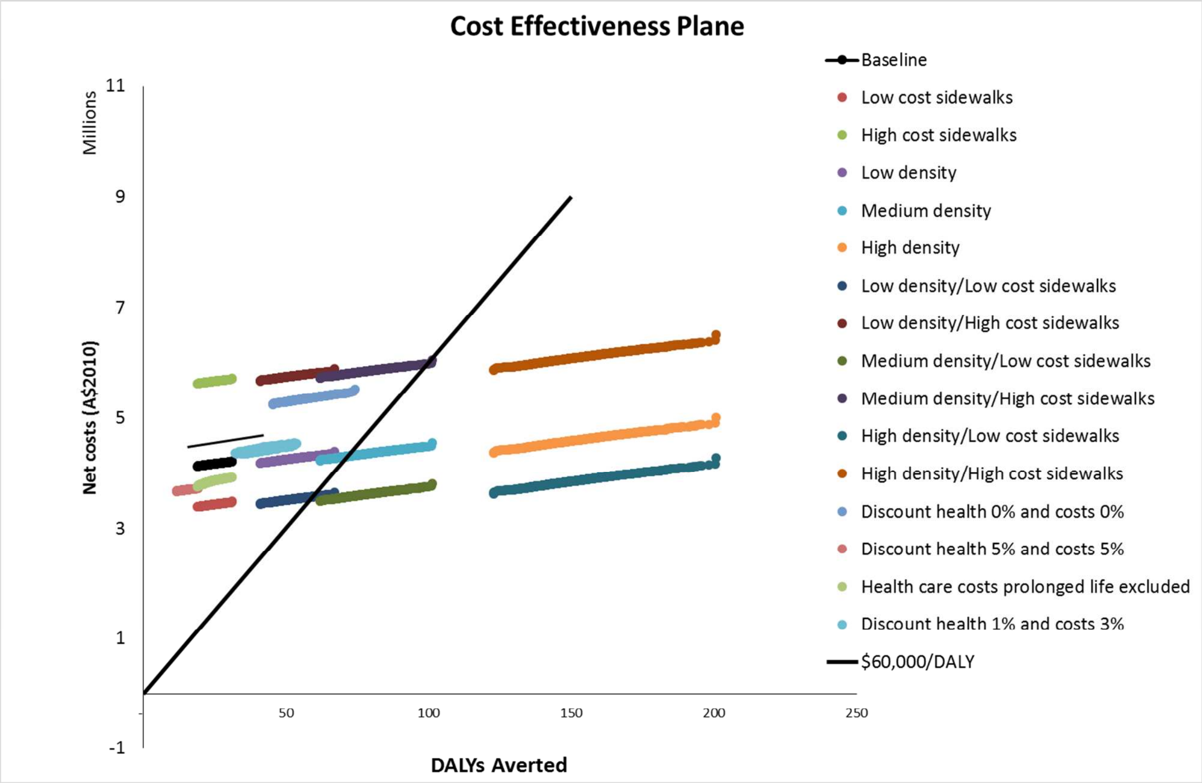
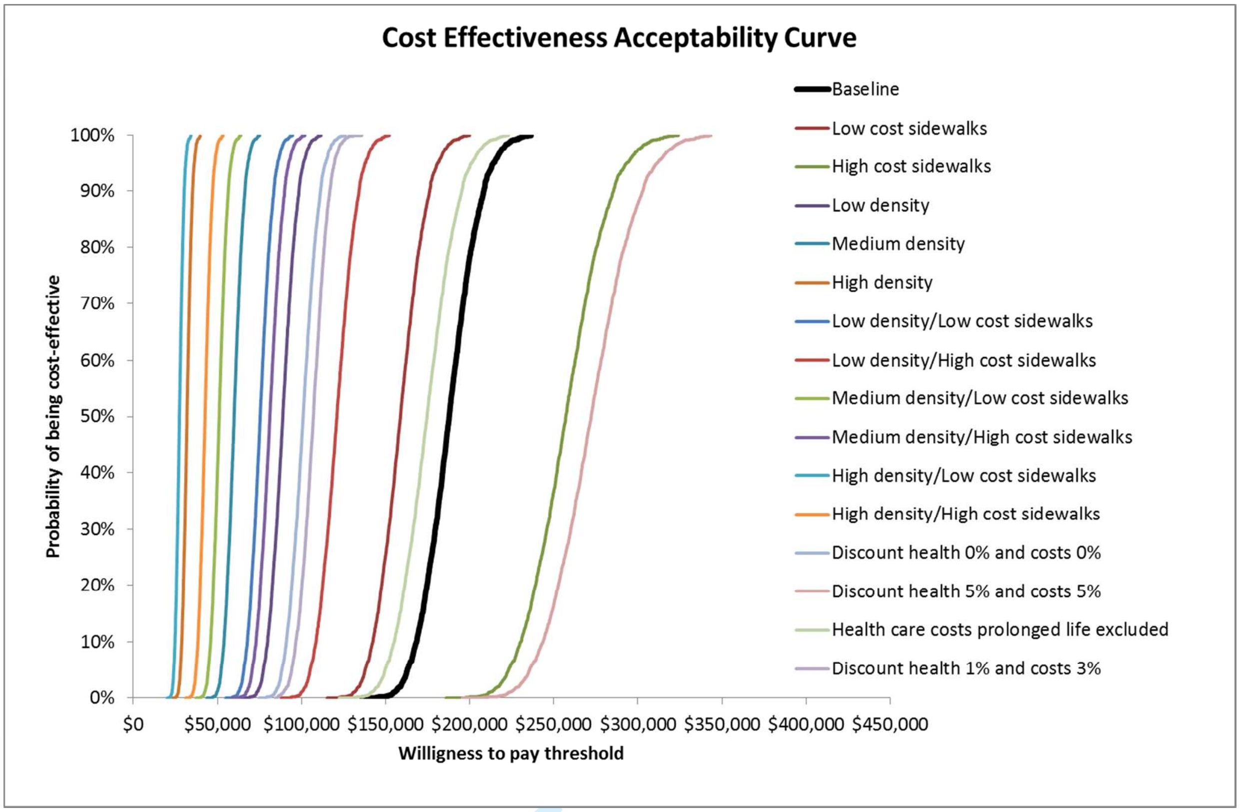
FIGURES

Figure 1. Cost effectiveness plane for investing in sidewalks in a neighbourhood, baseline and alternative scenarios compared to the status quo.

Figure 2. Cost effectiveness acceptability curve for investing in sidewalks in a neighbourhood, baseline and alternative scenarios compared to the status quo.


Cost Effectiveness Plane
Baseline
Low cost sidewalks
High cost sidewalks
Low density
Medium density
High density
Low density/Low cost sidewalks
Low density/High cost sidewalks
Medium density/Low cost sidewalks
Medium density/High cost sidewalks
High density/Low cost sidewalks
High density/High cost sidewalks
Discount health 0% and costs 0%
Discount health 5% and costs 5%
Health care costs prolonged life excluded
Discount health 1% and costs 3%
$60,000/DALY
Millions
11
9
7
5
3
1
-1
Net costs (A$2010)
50
100
150
200
250
DALYs Averted


Cost Effectiveness Acceptability Curve
Probability of being cost-effective
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
$0
$50,000
$100,000
$150,000
$200,000
$250,000
$300,000
$350,000
$400,000
$450,000
Willigness to pay threshold
Baseline
Low cost sidewalks
High cost sidewalks
Low density
Medium density
High density
Low density/Low cost sidewalks
Low density/High cost sidewalks
Medium density/Low cost sidewalks
Medium density/High cost sidewalks
High density/Low cost sidewalks
High density/High cost sidewalks
Discount health 0% and costs 0%
Discount health 5% and costs 5%
Health care costs prolonged life excluded
Discount health 1% and costs 3%

Cost effectiveness of investing in sidewalks as a means of increasing physical activity: a RESIDE modelling study- Supplementary material

Modelling the cost effectiveness of investing in sidewalks

The original ACE-prevention model [1] was adapted and updated from the original 2003 baseline year to assess the cost effectiveness of adding 10 km of sidewalk in each neighbourhood. The model assesses the cost effectiveness of the intervention for an Australian adult neighbourhood population, with baseline year 2010.

The model was set up in Excel (Microsoft Office 2010) and uncertainty analysis was performed with the add-in tool Ersatz (version 1.3; Epigear International).

Modelling health outcomes

Additional walking in the modelled population was translated into changes in *disability adjusted life-years* (DALYs) and incidence/prevalence of physical activity related diseases using a multi-cohort version of a proportional multi-state life table (MSLT) [2]. This MSLT model allows living individuals to be characterized into healthy or diseased states as opposed to the traditional life table that only permits two states (alive or dead). The term ‘proportional’ is in reference to the possibility of including multiple diseases whilst allowing for comorbidities.

Two populations are simulated in the model, the population of interest as it is (or is expected to be in the future, based on observed trends), and an identical population that is exposed to changes in physical activity. Each of these populations has a standard life table with all-cause mortality and sub-life tables for each one of the diseases causally related to physical activity. The Potential Impact Fraction (PIF) is used to link changes in exposure to incidence of physical activity related diseases. The PIF can be defined as the proportional change in disease incidence (or mortality) as a function of a change in exposure to a risk factor for that disease. For example, an increase in physical activity levels decreases the incidence of ischemic heart disease. In the proportional MSLT, this then leads to a decrease in the number of prevalent cases in later years at higher ages. Mortality due to a disease is modelled as a proportion of prevalence, and consequently mortality and years lived with disability (compared to the baseline population) follows a decrease in prevalence.

Changes in DALYs are calculated as the difference of DALYs lived between an Australian adult population that has been exposed to changes in physical activity compared to an identical population that does not experience any changes. DALYs are calculated by dividing both populations into five-year age cohorts groups (20-24 to 95+) and simulating each cohort in the life table until everybody dies or reaches the age of 100. Within the cohort each single year is adjusted for disability attributable to diseases included in the model and for disability caused by all other causes applying estimates for the Australian population [3].

A schematic description of the proportional multi-state life table is presented in Figure 1 only for the counterfactual population in the model (derived from the factual population).

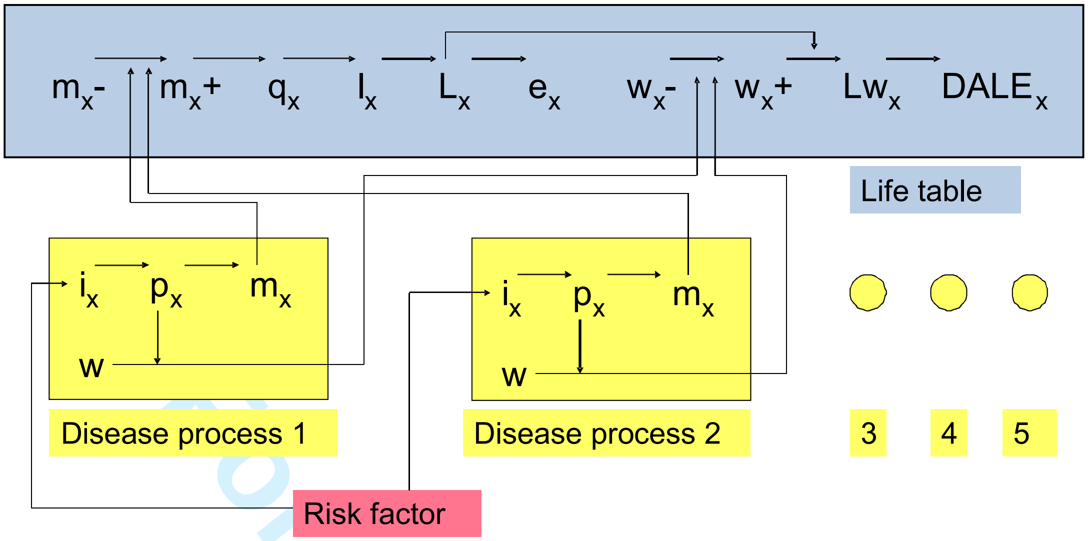


Figure 1 Schematic description of a proportional MSLT, indicating the interaction between life-table parameters and diseases parameters. All the parameters are age specific denoted with x, i is incidence, p is prevalence and m is mortality, w is disability adjustment, q is probability of dying, l is number of survivors, L is life years, Lw is disability adjusted life years and DALE is disability adjusted life expectancy, '-' denotes a denotes parameter related to diseases or causes not included in the models and '-' relates to all modelled diseases included in the model. A change in the determinant of health (physical activity) translates into changes in incidence (i_x), which changes disease specific prevalence (p_x) and mortality (m_x). Changes in prevalence translate into changes in disability adjustments (w).

Changes in diseases

In the MSLT the five physical activity related diseases are modelled applying a set of differential equations to describe the transition between the four states (healthy, diseased, death from the diseases and death from all other causes) [4] (Figure 2). Transition probabilities among the four states are based on rates of mortality, incidence, case fatality and remission. As explained before, the originator of change is incidence. To simplify the process remission is set to zero.

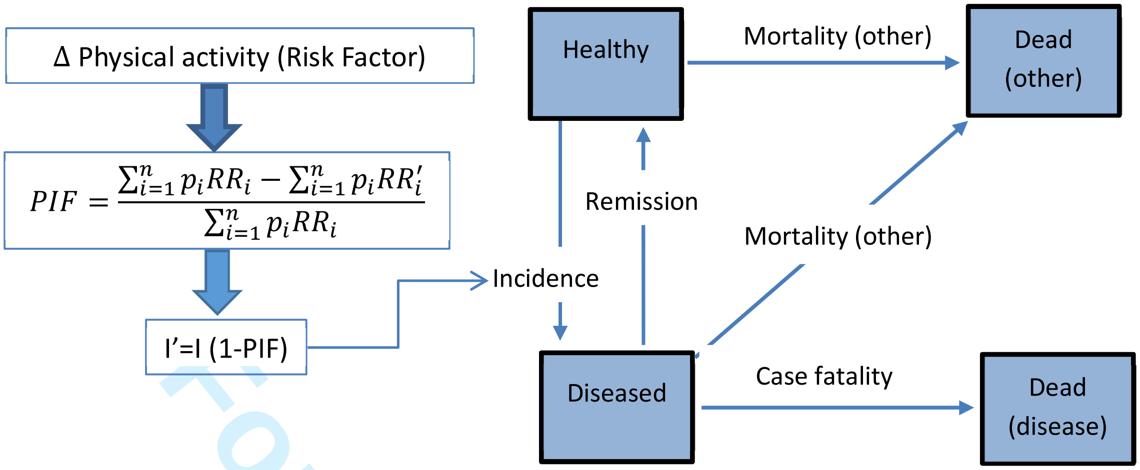


Figure 2 Conceptual disease model used for each of the physical activity related diseases and calculation of new incidence after the intervention. The disease conceptual model has four health states (healthy, diseased, dead from the disease and dead from other causes) and transition hazards between health states [4]. The 'relative risk PIF' [5] was used to estimate new levels of incidence due to changes in physical activity, where p_i is physical activity prevalence at level i (3 levels in this research), RR_i is the relative risk of physical activity for each of the diseases associated with i and RR_i' is the relative risk of physical activity for each disease associated after the intervention.

Data

Intervention effect (proportion taking up walking and additional minutes per week), epidemiological data and disease-related costs, relative risks of physical activity related diseases, physical activity prevalence, population demography (mortality and population), intervention duration and costs, population density and discounting rates are model input requirements.

Intervention effects were derived from the Heckman model estimates for the association between sidewalk and walking [6].

Epidemiological data for the five physical activity related diseases (ischemic heart disease, stroke, type 2 diabetes, colon cancer and breast cancer in women) were derived from the Global Burden of Disease 2010 study [3] with the help of DISMOD II to obtain parameters not explicitly reported (incidence and case fatality from prevalence and mortality).

Health care costs for the modelled diseases are from the original ACE-Prevention study (Disease Costs and Impact Study 2001 prepared by the Australian Institute of Health and Welfare) inflated applying the Health Price Index [7] (Table 1). Cost were obtained by dividing total cost related to a disease by the number of incident cases (breast cancer and colon cancer) or prevalent cases (ischaemic heart disease, stroke and diabetes type 2). Health care costs due to any other diseases that occur across the life course are included in the same fashion by inflating values from the original model (if people live longer they spend more in health care and the opposite if they live shorter lives).

Table 1 Health care cost per prevalent or incident case of disease

Age	Ischemic heart disease[a]	Stroke[a]	Type 2 diabetes[a]	Breast cancer[b]	Colon cancer[b]
Male					
<55	$3,930	$2,956	$669	-	$23,202
55–64	$2,638	$6,556	$876	-	$23,424
65–74	$2,208	$12,641	$1,012	-	$24,097
75-84	$2,006	$17,055	$848	-	$23,928
85+	$1,850	$21,625	$787	-	$25,588
Female					
<55	$2,430	$1,541	$671	$16,481	$22,733
55–64	$2,017	$2,773	$1,007	$13,921	$21,689
65–74	$2,116	$6,774	$1,113	$15,401	$22,869
75-84	$2,075	$17,427	$988	$16,856	$23,030
85+	$2,216	$26,106	$569	$16,609	$21,949

a. Cost per prevalent case of disease.
b. Cost per incident case of disease.
N.B. Costs are in Australian dollars, from the Disease Costs and Impact Study 2001 prepared by the Australian Institute of Health and Welfare and adjusted to the year 2010 [7].

Relative risks for the five physical activity related diseases are from meta-analyses carried out for the World Health Organization's *Comparative Quantification of Health Risks* [8] (Table 2). As type 2 diabetes is a risk factor for cardiovascular disease, the relative risks from the Asia Pacific Cohort Study Collaboration [9] were applied to estimate the risk of ischemic heart diseases and stroke among those with type 2 diabetes.

Table 2 Relative risks of disease due to physical inactivity

	Age	Inactive	Insufficient	Sufficient
Ischaemic heart disease[a]	15-69	1.71 (1.58-1.85)	1.44 (1.28-1.62)	1.00
	70-79	1.50 (1.38-1.61)	1.31 (1.17-1.48)	1.00
	80+	1.30 (1.21-1.41)	1.20 (1.07-1.35)	1.00
Ischaemic stroke[a]	15-69	1.53 (1.31-1.79)	1.10 (0.89-1.37)	1.00
	70-79	1.38 (1.18-1.60)	1.08 (0.87-1.33)	1.00
	80+	1.24 (1.06-1.45)	1.05 (0.85-1.30)	1.00
Type 2 diabetes	15-69	1.45 (1.37-1.54)	1.24 (1.10-1.39)	1.00
	70-79	1.32 (1.25-1.40)	1.18 (1.04-1.32)	1.00
	80+	1.20 (1.14-1.28)	1.11 (0.99-1.25)	1.00
Breast cancer (in women)	15-44	1.25 (1.20-1.30)	1.13 (1.04-1.22)	1.00
	45-69	1.34 (1.29-1.39)	1.13 (1.04-1.22)	1.00
	70-79	1.25 (1.21-1.30)	1.09 (1.01-1.18)	1.00
	80+	1.16 (1.11-1.20)	1.06 (0.98-1.15)	1.00
Colon cancer	15-69	1.68 (1.55-1.82)	1.18 (1.05-1.33)	1.00
	70-79	1.48 (1.36-1.60)	1.13 (1.01-1.27)	1.00
	80+	1.30 (1.20-1.40)	1.09 (0.97-1.22)	1.00

a. Relative risks of ischaemic heart disease and ischaemic stroke due to diabetes are 2.19 (1.81-2.66) and 2.64 (1.78-3.92) respectively [6].
N.B. Values shown are the mean and 95% confidence intervals.

Prevalence of physical activity per 5-year age/sex group was derived from the National Nutrition and Physical Activity Survey Basic Confidentialised Unit Record File (CURF) [10] with the help of Stata (StataCorp. 2013. *Stata Statistical Software: Release 13*. College Station, TX: StataCorp LP). We weighted the sample data applying person weights provided in the data set. Respondents were asked questions on time spent on four types of activities: walking for transport, walking for fitness, vigorous and moderate physical activity that were then multiplied by the Metabolic Equivalent of Task per minutes (MET-minutes) [11] to obtain weekly energy expenditure (duration of physical activity (mins) * intensity factor walking for recreation/fitness=3.5, walking for transport=3.5, moderate=5, vigorous=7.5). Three categories of physical activity were created according to the weekly energy expenditure: sufficiently active (≥750 MET-minutes per week), insufficiently active (100-700 MET-minutes per week) and inactive (<100 MET-minutes per week) (Figure 3). Average energy expenditure by sex (assumed the same across all age groups) for the calculation of

diseases relative risk per age and sex were obtained by multiplying the corresponding MET minutes by each of the types of physical activity and obtained the average MET-minutes per each of the three physical activity categories.

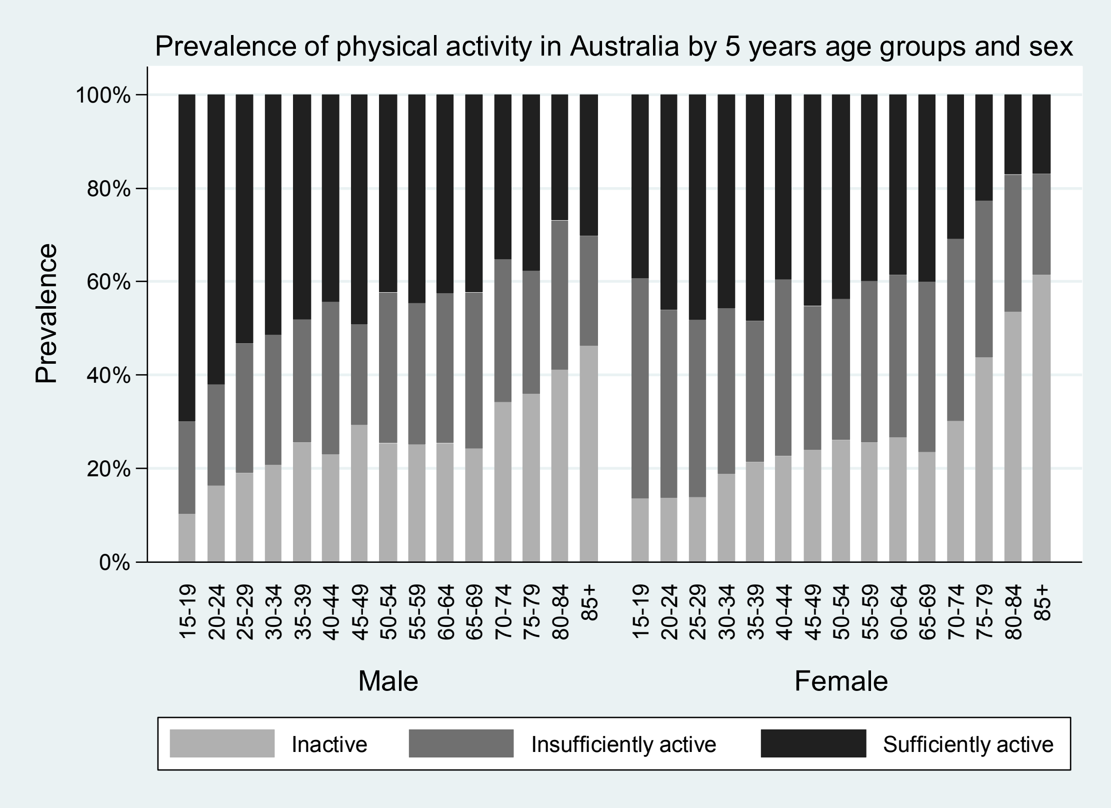


Figure 3 Prevalence of physical activity in Australia (from the National Health Survey 2011-2013)

Population and mortality data inputs are 2010 estimates from the Australian Bureau of Statistics (ABS) [12, 13].

Intervention

For the intervention we used estimates for the population that would be affected by the intervention which we derived from residential density and intervention costs (Table 3).

Table 3 Intervention parameters

Parameter	Value	Source/Comments
Density (net density)		
Base	9 (19,000)[a]	Empirical findings from Falconer, Newman and Giles-Corti [14 p. 288]
For sensitivity analysis		
Low	20 (41,000)	Heart Foundation "Does Density matter?" , 2014, Falconer, Newman and Giles-Corti [14]
Medium	30 (62,000)	Heart Foundation "Does Density matter?" , 2014, Falconer, Newman and Giles-Corti [14]
High	60 (123,000)	Heart Foundation "Does Density matter?" , 2014, Falconer, Newman and Giles-Corti [14]
Sidewalk Cost[b]		
Base scenario	$\$172/m^2$ (2012/13)	Liverpool City Council [15]
For sensitivity analysis		
Low	$\$150/m^2$ (2014)	WalksVictoria [16]
High	$\$236/m^2$ (2012/13)	Liverpool City Council [15]
Useful Life of Sidewalk		
Base	15 years	Quoted by Paul McEvoy in Gunn, Lee, Geelhoed, Shiell and Giles-Corti [17]
Project lifetime		
Base	30 Years	As per in ACE-prevention [18]

a. Based on 2.55 adults per dwelling.

b. Factored to 1.5 meter wide (Liveable Neighbourhood guidelines) and set to baseline year 2010.

Discount rate health and costs

Discounting was applied to health benefits, costs offsets and intervention costs. There has been an ongoing discussion in regards to the appropriate discount rate and whether health benefits should be discounted [19]. Here we followed the recommendations by Gold et al [20] and applied 3% for health benefits and costs (intervention costs and cost offsets) for the base case scenario (the recommendations says 3% or 5%). For sensitivity analyses we varied the discounts rates to 0% for health effects [19] and 5%, and included a scenario in which costs were discounted at 3% and health effects at 1% [21].

Predictive validity

There are multiple techniques to assess the validity of the model. Sargent [22] discusses that a model is developed for a specific purpose and thus its validity should be tested with respect to his purpose. The model developed here assessed how increases in walking affected neighbourhood adult population health, where health was measured using changes in DALYs. The formal validity of the model was checked by several investigators. We tested

for extreme conditions. Specifically, we tested the model outcome when change in walking was equal to zero, and we obtained the expected zero change in outcomes. Moreover, we tested for internal validity by running the model several times to compare the consistency of the results.

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Cost effectiveness of investing in sidewalks as a means of increasing physical activity: a RESIDE modelling study

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ABSTRACT

Background

Studies consistently find that supportive neighbourhood built environments increase physical activity by encouraging walking and cycling. However, evidence on the cost-effectiveness of investing in built environment interventions as a means of promoting physical activity is lacking. In this study we assess the cost-effectiveness of increasing sidewalk availability as one means of encouraging walking.

Methods

Using data from the RESIDE study in Perth, Australia, we modelled the cost impact and change in Health Adjusted Life Years (HALYs) of installing additional sidewalks in established neighbourhoods. Estimates of the relationship between sidewalk availability and walking were taken from a previous study. Multi-state life table models were used to estimate HALYs associated with changes in walking frequency and duration. Sensitivity analyses were used to explore the impact of variations in population density, discount rates, sidewalk costs and the inclusion of unrelated health care costs in added life years.

Results

Installing and maintaining an additional 10 km of sidewalk in an average neighbourhood with 19,000 adult residents was estimated to cost A$4.2 million over 30 years and gain 24 health-adjusted life years (HALYs) over the lifetime of an average neighbourhood adult resident population. The incremental cost-effectiveness ratio was

A$176,000/HALY. However, sensitivity results indicated that increasing population densities improves cost-effectiveness.

Conclusions

In low density cities such as in Australia, installing sidewalks in established neighbourhoods as a single intervention is unlikely to cost- effectively improve health. Sidewalks must be considered alongside other complementary elements of walkability, such as density, land use mix and street connectivity. Population density is particularly important because at higher densities, more residents are exposed and this improves the cost-effectiveness. Health gain is one of many benefits of enhancing neighbourhood walkability and future studies might consider a more comprehensive assessment of its social value (e.g. social cohesion, safety and air quality).

Article summary

Strengths and limitation of this study

- The well-established multi-state multi-cohort life table approach was used to estimate the potential health benefits of investing in sidewalks to encourage physical activity
- Health outcomes considered included reductions in mortality and morbidity, and health-adjusted life years gained
- Findings were adjusted for self-selection effects
- Effect estimates for the association of sidewalk availability with physical activity are potentially subject to recall bias
- Only one interventions is considered in this study, however, to impact on walking and health, there is a need for integrated built environment interventions.

INTRODUCTION

Physical inactivity is an important risk factor for many chronic diseases including diabetes, cardiovascular disease and some types of cancer [1]. In Australia, physical inactivity ranks eighth as a risk factor for death and ninth as a risk factor for disability adjusted life-years (DALYs) [2]. Yet despite the known benefits, too few adults in Australia [3] and elsewhere [4, 5] participate in levels of physical activity optimal for health. Even small increases in physical activity reduce the risk of chronic disease and provide health benefit [6]. Creating supportive built environments can cause positive shifts in population levels of physical activity and significantly reduce the burden of disease and related health care spending [7].

There is increasing attention for the role of the built environment, and in particular neighbourhood urban form, in either facilitating or inhibiting physical activity [8]. Several neighbourhood built environment characteristics, including the mix and diversity of land uses and destinations, population or residential density, and street and pedestrian connectivity, are consistently found to be positively associated with physical activity, and in particular walking [9-12]. Other built environment attributes are also important for supporting walking such as access to transit, availability and quality of sidewalks/ footpaths, street appeal or aesthetics, and personal and traffic safety [13-17, 10]. These built environment characteristics collectively contribute to the ‘walkability’ of a neighbourhood, which is found to be positively associated with walking and other physical activity behaviours [9, 18]. Creating ‘walkable’ neighbourhoods would also produce co-benefits and meet other social objectives such as sustainable transportation, reduction in air pollution and traffic noise, and increased social connectivity [19, 20]. If these health and social benefits could be realised at a reasonable cost then environmental interventions that improve the walkability of residential neighbourhoods may be a cost-effective means of promoting health and well-being.

There are few economic evaluations of environmental interventions and most of the available evidence relates to designated walking trails or transport-related infrastructure, such as cycle paths [21-23]. However, none of these studies adjusted effect estimates for bias introduced by residential self-selection [24] and only one [23] controls for other built environment characteristics. A systematic review found the median benefit to cost ratio to be 5:1, suggesting that every $1 invested in transport-related infrastructure generates benefits worth $5 (including the financial value of reduced demand on the health care system) [25]. Despite this important finding, the authors hesitated from drawing policy-relevant conclusions citing a lack of transparency and variation in the methods employed in studies as a cause for concern. The need to account more accurately for the effect of built environment measures on physical activity was highlighted in a recent systematic review of transport economic evaluations [26].

Others have monetized the health benefits of urban form in relation to walking and health. Boarnet, Greenwald and McMillan [27] used regression analysis on travel survey data from Portland, Oregon, to quantify the impact of built environmental features on distance walked. Walking was translated into lives saved, with each life valued in dollar terms using published estimates of the value of a statistical life ranging from US$2.5 million to US$7.4 million per life saved (US$ 2006). Their analysis suggested that two lives would be saved per year for every 1000 people exposed to a more walkable environment. While this finding is promising, missing from the work was any attempt to quantify the cost of the environmental interventions that might help realise these benefits.

Whilst recognising the need to evaluate the complementary effects of each component of a neighbourhood that collectively enhances walkability, this paper begins this important work by focussing on one aspect, namely the presence of sidewalks. Building sidewalks is something that planners could require in all new housing, and which could be retrofitted in established neighbourhoods.

This study considers the cost-effectiveness of spending to extend the length of sidewalks in a neighbourhood to increase levels of walking and improve health. The effect estimates applied in this modelling exercise were adjusted for other built environment features (implicitly holding all other features of the neighbourhood environment constant) and for residential self-selection, which allows for the evaluation of the independent and unbiased effect of increasing sidewalks.

METHODS

Overview

This economic evaluation involved four stages: 1) estimate the effect of sidewalks on walking; 2) translate the expected increase in walking into a increase in health-adjusted life years (HALYs) gained and health care costs; 3) estimate the costs of extending sidewalk length; and 4) derive estimate of economic value of investing in sidewalks to increase physical activity in terms of the cost per HALY gained. A health sector perspective was used in which the costs of sidewalks (as a health-promoting intervention) were included. An intervention of 30 years duration was assumed, a lifetime time horizon was applied, and costs and benefits were discounted at 3% (base case scenario) to 2010 values. The 3% rate was chosen following the recommendation by the US Panel on Cost-Effectiveness in Health and Medicine [28].

Estimate of effect of sidewalks on walking

RESIDE data

Data for this stage of the evaluation were drawn from the RESIDential Environments Study (RESIDE) in Perth, Western Australia. RESIDE is a longitudinal study examining the relationship between urban design and a number of social outcomes including physical activity. The opportunity for the RESIDE study arose when, in 1998, the Western Australia state government introduced new planning guidelines (the Liveable Neighbourhood Guidelines) incorporating 'New Urbanist' principles. The RESIDE study followed people relocating to new houses being built in one of 74 new housing developments, some of which were designed according to the Liveable Neighbourhoods guidelines. Information on the RESIDE project is detailed elsewhere [29]. The RESIDE dataset contains information on 1,813 people of whom 59% were female, 81% were married or in de facto relationships, 67% have children living at home, 22% were university educated, and 53% were either overweight or obese (average BMI was 26.05) [29].

Model estimates

We took estimates of the relationship between sidewalk length and walking behaviour from the RESIDE cross-sectional baseline survey in this economic evaluation [30]. Data included self-reported neighbourhood-based transportation and recreational walking, socio-demographic characteristics, attitudes towards walking, and variables related to residential self-selection (i.e., access to services, recreation, and schools, pedestrian and cycling friendly streets, and housing variety). Neighbourhood-based transportation and recreational walking had been measured using the Neighbourhood Physical Activity Questionnaire, which provides reliable estimates of the proportion of people who walk and the average minutes spent walking in a usual week, within and outside the neighbourhood [31]. This degree of specificity has proved useful in linking walking for different purposes (transport, leisure) with particular neighbourhood attributes. The built environment within 1.6km around participants' homes had been assessed using Geographical Information Systems and satellite imagery to derive objectively-determined measures of neighbourhood walkability (i.e., land use mix, residential density, and street connectivity) [32] and sidewalk length. A Heckman two-staged regression model had then been used to estimate the association between sidewalk length in the neighbourhood and (a) the proportion of people walking for transport or leisure in the neighbourhood, and (b) the total minutes spent walking in the neighbourhood in a usual week among those who reported any walking [33]. McCormack et al. [33] provide a detailed description of the method and results of the Heckman modelling, but in brief, the decision about whether or not to walk was estimated using a multivariate Probit regression followed by a sample selection-bias corrected ordinary least squares regression for minutes spent walking. Estimates of the association between sidewalk length and neighbourhood walking were then adjusted for differences in walkability, attitude towards walking, neighbourhood self-selection , age, gender, and education [33]. McCormack et al. [33] included neighborhood preferences in the probit and linear regression models to adjust for the effect of residential self-selection on walking.

Modelling Health Outcomes and Health Care Costs

To translate the Heckman model estimates of walking as a function of sidewalk length into an estimate of gained HALYs and health care costs avoided we used the mathematical model developed for the Assessing Cost Effectiveness in Prevention (ACE-Prevention) project [34]. Baseline health and cost parameters were updated from 2003 to 2010. See supplementary material for further detail.

Gained HALYs and costs were measured over the lifetime of a 2010 Australian neighbourhood adult population. A macro simulation approach was used to calculate changes in HALYs arising from expected changes in physical activity levels due to walking following a hypothetical increase in sidewalk length. We applied a proportional multi-state multi-cohort life table model in which five physical activity related diseases were explicitly modelled, comparing the lifetime number of HALYs for a population that is exposed to the intervention to an identical population under status quo conditions [35]. Epidemiological data for the diseases (ischemic heart disease, stroke, type 2 diabetes, colon cancer and breast cancer in women) were derived from the Global Burden of Disease 2010 [36] study with the help of DISMOD II [37] to obtain parameters not explicitly reported (incidence and case fatality from prevalence and mortality). HALYs are estimated as years of life lived adjusted for health-related quality of life, using Global

Burden of Disease disability weights [38] . For more detail, please refer to the Supplementary Material.

Intervention Costs

The intervention was defined as spending to increase the length of sidewalks by 10km in each 1.6 km road network buffer surrounding a participant's home and maintaining this for 30 years. The cost of installing a standard sidewalk was determined to be A$172 (2012/2013) per square metre based on estimates of actual sidewalk replacement costs obtained from council documents [39-41]. Previous research used a value of A$70 per linear meter for a sidewalk of 1.8m in width [16], however, more recent evidence suggests that the price per square meter is likely to be higher [39-41]. The initial capital cost and periodic maintenance costs were included, assuming sidewalk replacement after 15 years.

Exposure

More people than just the survey participants will benefit from the investment in sidewalks, and so we also need to take into account residential density to compute the number of people 'exposed' to the intervention. Planning guidelines for Perth from 2003 suggest an average residential density of 9 dwellings/hectare in low density areas [42]. Assuming an average of 2.55 adults per dwelling, this yields an estimate of 19,000 potential beneficiaries within a 1.6km circular area. We use this figure in our baseline estimate and revisit the assumption in our sensitivity analysis and discussion.

Intervention Cost-Effectiveness

An incremental cost-effectiveness ratio (ICER) is evaluated for the intervention by comparing model outcomes given current levels of physical activity with those that would be expected following an increase in the length of sidewalks in each neighbourhood. The net costs of the intervention are the costs of installing and maintaining the sidewalks plus the net effect that changes in health have on health care costs in future. The reduction in diseases related to physical inactivity lowers treatment cost in the short and medium term, but it also means that new health care costs may be incurred by people who now go on to develop unrelated conditions in their added years of life.

Ninety-five percent uncertainty intervals were determined for all outcome measures by Monte Carlo simulation (2,000 iterations), using the Excel add-in tool Ersatz (Epigear, Version 1.01). Uncertainty distributions around input parameters are described in Table 1. The results of the Monte Carlo analysis were then used to determine the probability of intervention cost-effectiveness against a cost-effectiveness threshold of A$60,000 per HALY [43, 44].

Table 1. Uncertainty input parameters

Parameter	Mean (SD)	Distribution	Source
Proportion doing any walking	62.40% (19.86%)	Beta	[33]
Extra walkers per additional 10km sidewalk (RESIDE sample)	0.66% (9.68%)	Beta	[33]
Average minutes walked per walker	151.10 (123.15)	Lognormal	[33]
Extra minutes walked per week per 10km sidewalk	5.26 (2.93)	Lognormal	[33]
Disease cost offset	See supplementary	Uniform	Australian Institute of Health

	material table 1		and Welfare Impacts Study 2001. Maximum/minimum assumed at ±25% of mean value
Relative risks of diseases	See supplementary material table 2	Normal (ln RR)	Physical activity [1] and Diabetes risks [45]

In addition, we vary the cost of sidewalk construction and maintenance, the residential density in the neighbourhood where the new sidewalks are located, and the discount rate in a series of one- and two-way sensitivity analyses. We also combine the cost of sidewalks with residential density to find the most cost-effective mix. All scenarios including the baseline are presented in Table 2.

Table 2. Evaluated scenarios

Scenarios	Cost sidewalk per square meter (A$2010/m^2)	Residential density: dwelling per ha (number of adults*)	Discount rate (%) costs / health	Other health care costs in added life years excluded
1. Baseline	166	9 (19,000)	3	No
2. Low cost sidewalk	136	9 (19,000)	3	No
3. High cost sidewalk	227	9 (19,000)	3	No
4. Low density	166	20 (41,000)	3	No
5. Medium density	166	30 (62,000)	3	No
6. High density	166	60 (123,000)	3	No
7. Low density/ Low cost sidewalk	136	20 (41,000)	3	No
8. Low density/ High cost sidewalk	227	20 (41,000)	3	No
9. Medium density/ Low cost sidewalk	136	30 (62,000)	3	No
10. Medium density/ High cost sidewalk	227	30 (62,000)	3	No
11. High density/ Low cost sidewalk	136	60 (123,000)	3	No
12. High density/ High cost sidewalk	227	60 (123,000)	3	No
13. Discount health 0% and costs 0%	166	9 (19,000)	0	No
14. Discount health 1% and costs 3%	166	9 (19,000)	3/1	No
15. Discount health 5% and costs 5%	166	9 (19,000)	5	No
16. Health care costs prolonged life excluded	166	9 (19,000)	3	Yes

*1.6 km road network buffer

RESULTS

Incremental Cost-Effectiveness

In the baseline scenario, the cost of installing and maintaining an extra 10 km of sidewalks is A$4.1 million per neighbourhood. This investment is expected to gain 24 HALYs over the life span of the neighbourhood adult population (95% uncertainty interval (UI) 20 to 28) (Table 3, Scenario 1. Baseline). After taking into account the net effect on health care costs the total cost increases to A$4.2 million. The incremental cost-effectiveness ratio (ICER) is A$176,000 per HALY gained (95% UI A$148,000 to A$203,000), which lies well above the A$60,000/HALY threshold (Figure 1). Under the baseline scenario assumptions, there was 0% probability of this intervention being under A$60,000 per HALY (Table 4 and Figure 2).

Table 3.Cost Effectiveness Results

Scenarios	HALYs	Intervention cost[b] (A$)	Health care cost offsets[a] (A$)	Costs prolonged life (A$)	Net Cost (A$)	ICER (A$)
1. Baseline	24	4,077,694	-232,232	313,910	4,159,373	175,782
	(20 , 28)		(-185,343 , -288,222)	(264,636 , 374,670)	(4,134,899 , 4,186,344)	(147,983 , 203,463)
2. Low cost sidewalk	24	3,340,761	-232,232	313,910	3,422,440	144,635
	(20 , 28)		(-185,343 , -288,222)	(264,636 , 374,670)	(3,397,967 , 3,449,411)	(121,911 , 167,330)
3. High cost sidewalk	24	5,576,124	-232,232	313,910	5,657,802	239,115
	(20 , 28)		(-185,343 , -288,222)	(264,636 , 374,670)	(5,633,329 , 5,684,774)	(201,101 , 276,963)
4. Low density	51	4,077,694	-501,132	677,386	4,253,948	83,303
	(44 , 61)		(-399,951 , -621,953)	(571,056 , 808,499)	(4,201,137 , 4,312,149)	(70,416 , 96,162)
5. Medium density	78	4,077,694	-757,809	1,024,339	4,344,224	56,251
	(67 , 92)		(-604,803 , -940,514)	(863,548 , 1,222,608)	(4,264,364 , 4,432,236)	(47,635 , 64,908)
6. High density	154	4,077,694	-1,503,396	2,032,157	4,606,455	30,057

	(132,182)		(-1,199,852 , -1,865,858)	(1,713,168 , 2,425,497)	(4,448,024 , 4,781,059)	(25,527 , 34,652)
7. Low density/Low cost sidewalk	51	3,340,761	-501,132	677,386	3,517,015	68,869
	(44 , 61)		(-399,951 , -621,953)	(571,056 , 808,499)	(3,464,205 , 3,575,216)	(58,276 , 79,413)
8. Low density/High cost sidewalk	51	5,576,124	-501,132	677,386	5,752,378	112,652
	(44 , 61)		(-399,951 , -621,953)	(571,056 , 808,499)	(5,699,567 , 5,810,579)	(95,054 , 130,236)
9. Medium density/Low cost sidewalk	78	3,340,761	-757,809	1,024,339	3,607,291	46,706
	(67 , 92)		(-604,803 , -940,514)	(863,548 , 1,222,608)	(3,527,432 , 3,695,303)	(39,604 , 53,933)
10. Medium density/High cost sidewalk	78	5,576,124	-757,809	1,024,339	5,842,654	75,659
	(67 , 92)		(-604,803 , -940,514)	(863,548 , 1,222,608)	(5,762,794 , 5,930,665)	(63,987 , 87,309)
11. High density/Low cost sidewalk	154	3,340,761	-1,503,396	2,032,157	3,869,523	25,246
	(132,182)		(-1,199,852 , -1,865,858)	(1,713,168 , 2,425,497)	(3,711,091 , 4,044,126)	(21,468 , 29,078)
12. High density/High cost sidewalk	154	5,576,124	-1,503,396	2,032,157	6,104,885	39,840
	(132,182)		(-1,199,852 , -1,865,858)	(1,713,168 , 2,425,497)	(5,946,453 , 6,279,489)	(33,798 , 45,955)

13. Discount health 0% and costs 0%	57 (49 , 67)	4,980,000	-451,438 (-360,947 , -559,008)	815,905 (691,928 , 969,496)	5,344,467 (5,279,735 , 5,422,494)	94,735 (80,509 , 108,668)
14. Discount health 1% and costs 3%	42 (36 to 49)	4,077,694	-231,952 (-186,346, -284,915)	580,915 (495,475 , 683,747)	4,426,658 (4,373,856, 4,489,457)	106,881 (92,107 , 122,033)
15. Discount health 5% and costs 5%	15 (12 , 17)	3,666,193	-159,890 (-127,587 , -198,580)	182,938 (153,130 , 219,227)	3,689,241 (3,673,755 , 3,706,601)	254,664 (213,699 , 295,717)
16. Health care costs prolonged life excluded	24 (20 , 28)	4,077,694	-232,232 (-185,343 , -288,222)	313,910 (264,636 , 374,670)	3,845,462 (3,789,472 , 3,892,351)	162,609 (134,756 , 190,513)

[a] Negative costs indicate savings.
[b] No uncertainty for intervention costs was assumed.

Table 4. Probability of being under A$60,000 per HALY threshold

Scenario	Probability
1. Baseline	0%
2. Low cost sidewalk	0%
3. High cost sidewalk	0%
4. Low density	0%
5. Medium density	79%
6. High density	100%
7. Low density/Low cost sidewalk	5%
8. Low density/High cost sidewalk	0%
9. Medium density/Low cost sidewalk	100%
10. Medium density/High cost sidewalk	0%
11. High density/Low cost sidewalk	100%
12. High density/High cost sidewalk	100%
13. Discount health 0% and costs 0%	0%
14. Discount health 1% and costs 3%	0%
15. Discount health 5% and costs 5%	0%
16. Health care costs prolonged life excluded	0%

************************(Insert Figure 1 about here) ************************

************************(Insert Figure 2 about here) ************************

Sensitivity Results

The results are extremely sensitive to some of the assumptions made in the analysis, especially in respect to changes in residential density, which materially affects the number of people benefiting from the intervention (Table 4). High residential density, or medium density if the cost of installing sidewalks is low, both generate ICERs consistently below the A$60,000 per HALY benchmark (Table 4 and Figure 2). For the medium density scenario, the probability of being under this threshold was 79%.

DISCUSSION

Principal findings

While sidewalks are important in supporting walking, these results show that investing in increasing the length of sidewalks in a neighbourhood, independent of other modifications to create a more walkable neighbourhood, is unlikely to be a cost-effective method of improving health at the existing (low) levels of residential density in Perth. That is to say, other means of increasing physical activity such as GP 'prescriptions' for physical activity, social marketing campaigns and supported use of pedometers were estimated to generate health benefits at lower net cost [34].

The analysis is limited to the outcomes associated with the most important diseases related to physical inactivity. Other health benefits, including improved safety for pedestrians, and broader social benefits such as those related to less reliance on motor vehicles, or to any increase in sense of community that results from seeing more of one's neighbours on the street, have not been included because we lack data on the impact on these measures [46, 47]. Thus, one cannot conclude from this work that investing in extending sidewalks is not cost-effective per se. Health gain is, to some extent, an externality or fortunate by-product of decisions that make neighbourhoods more walkable and ultimately more liveable. A more complete evaluation would reflect the value of all outcomes of importance.

The model estimates used for the association between sidewalks and walking also have limitations [33]. The estimates of walking, while specific to the neighbourhood context, were self-reported and therefore prone to recall and memory errors. Further, not all walking trips, either for transportation or recreation, are within the neighbourhood. Our context-specific approach, which matched neighbourhood sidewalks with neighbourhood walking, is a strength of this study. However, this approach may underestimate the total influence of sidewalks on walking, as some walking that originated from within the neighbourhood may have also included some walking outside the neighbourhood. Furthermore, sidewalk provision may also support more vigorous-intensity physical activities such as jogging and running, which can provide health benefits over and above those provided by more moderate-intensity physical activity such as walking [48, 49]. Since this was a sample of mostly younger and middle-aged people who were about to move into new housing developments in suburban Australia, the external validity of our findings is greatest when applied in similar settings. The more the population of interest differs from out study population, the more caution should be applied in the use of our findings. However, in situations where better suited alternative data are not available, our estimates could serve as a 'best available estimate' if the alternative is no estimate at all, with the risk that the health benefits of walking associated with sidewalks are ignored in the decision making process.

Sidewalk within the broader context

Investment in sidewalks might have a bigger marginal impact on physical activity and produce more health benefits if it were accompanied by complementary efforts to improve other aspects of walkability such as the number and mix of destinations that people can walk to (land use mix), street connectivity and the aesthetic quality of the physical environment. People not only need something to walk on, but also somewhere to walk to. Such a comprehensive approach is likely to have both additive and synergistic benefits as each component of walkability complements the others. It might be also necessary to have other health promotion strategies in place, in addition to the built environment changes, to maximise the impact of this investment on physical activity.

Notably, our results show strongly the importance of residential density. In higher density neighbourhoods the fixed costs of neighbourhood improvements are spread over more people leading to greater overall benefit, which improves cost-effectiveness. By international standards, density in Australia is very low. While one of the aims of the Western Australian Liveable Neighbourhood Guidelines is to increase density, density remained low [42], there is still a demand for large houses on large blocks in Australian cities, with little appetite to mandate higher densities. Nevertheless, policies such as the Liveable Neighbourhood Guidelines are influential in changing practice, and average densities of up to 19 houses per hectare are now being observed in green-field developments in Perth [50]. Although that is an improvement over 9 houses per hectare, at 19 houses per hectare the population density is expected to be approximately 40,000 people in a neighbourhood, which implies zero probability for the installation of sidewalks to be cost-effective from the perspective of this study (Table 2).

Other studies found more favourable cost-effectiveness results for sidewalks. For example, using a sophisticated spatial analysis but what they considered a ‘back-of-the-envelope’ economic analysis, Guo and Gandavarapu [23] found that increased sidewalk prevalence in Dane County, Wisconsin, USA, would deliver a cost-benefit ratio of 1.87. The contrast with our findings could be due to a range of factors, including the inability in that study to adjust for residential self-selection, the assumption that additional energy spent on active transport directly translate to lower obesity rates (without dietary compensation) where we modelled the impact via physical activity, and differences in the built environment such as housing density.

Policy implications

Retro-fitting established neighbourhoods to improve walkability is challenging as it involves changing existing infrastructure and housing stock. Such change is often resisted by residential and government bodies and communities. Infrastructure improvements likely to improve health will require a comprehensive long-term strategy involving integrated planning of infrastructure, housing, transport, land use and urban design [51]. To this end, the development industry has an important role to play in providing leadership in developing new models for homes in green-field sites that meet the need for more compact developments for a healthier and more sustainable future. Similarly, planning regulations relating to shared occupancy, infill development and housing renewal should aim to increase higher density housing supply, resulting in greater use of existing infrastructure such as sidewalks, transportation, public open space and utilities.

The challenges of retro-fitting existing neighbourhoods and our findings here on the significance of walking draw attention to the need to design pedestrian-friendly neighbourhoods from the outset to facilitate active transport and recreational walking.

CONCLUSION

This work adds to a growing evidence base examining the cost-effectiveness of intervening in the built environment as a means of increasing physical activity and improving health and social outcomes. It points to the potential offered by neighbourhood redevelopment yet highlights the need for a comprehensive strategy that seeks both to improve all elements of walkability including land use mix and street connectivity. In particular it highlights the importance of residential density as a mechanism through which the cost effectiveness of infrastructure is affected because the higher the density, the lower the fixed cost per person who has access to that infrastructure.

COMPETING INTEREST

None to declare.

AUTHORS' CONTRIBUTIONS

A. Shiell, B. Giles-Corti, J.L. Veerman and G. McCormack developed the initial design of the study, oversaw and supervised the empirical work and contributed in drafting the first manuscript. L. Gunn and B. Zapata-Diomedi revised and amended the first manuscript and all authors revised the final version of the paper. L. Cobiac set up the original economic model and B. Zapata-Diomedi revised and updated the economic model with demographic, cost and epidemiologic data, ran the models and wrote the results. B. Zapata-Diomedi drafted the abstract and appendix and J.L. Veerman revised them. L. Gunn, G. McCormack and A. Shiell provided the interventions costs. A.M. Mantilla-Herrera produced the epidemiological estimates. All authors contributed to and commented on the final version of the manuscript.

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DATA SHARING STATEMENT

The model to estimate health outcomes and health care costs is available on request from the first author of this study.

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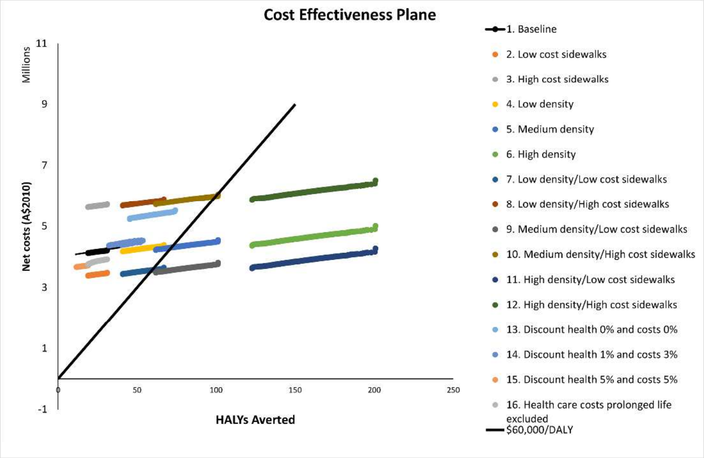
FIGURES

Figure 1. Cost effectiveness plane for investing in sidewalks in a neighbourhood, baseline and alternative scenarios compared to the status quo.

Figure 2. Cost effectiveness acceptability curve for investing in sidewalks in a neighbourhood, baseline and alternative scenarios compared to the status quo.



Cost effectiveness plane for investing in sidewalks in a neighbourhood, baseline and alternative scenarios compared to the status quo

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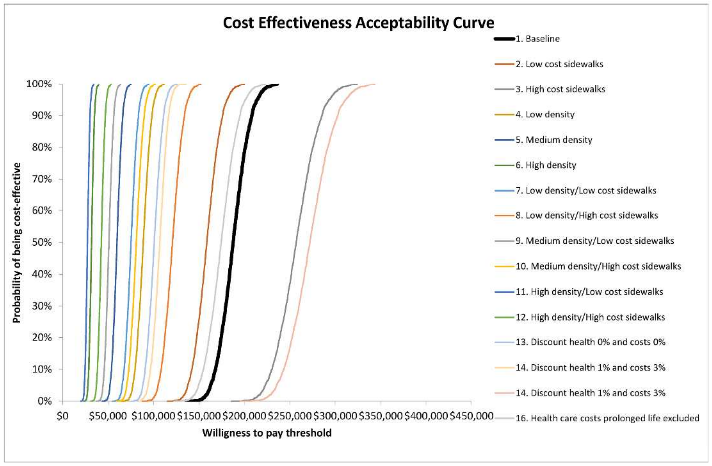

Cost effectiveness acceptability curve for investing in sidewalks in a neighbourhood, baseline and alternative scenarios compared to the status quo.

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Cost effectiveness of investing in sidewalks as a means of increasing physical activity: a RESIDE modelling study- Supplementary material

Modelling the cost effectiveness of investing in sidewalks

The original ACE-prevention model [1] was adapted and updated from the original 2003 baseline year to assess the cost effectiveness of adding 10 km of sidewalk in each neighbourhood. The model assesses the cost effectiveness of the intervention for an Australian adult neighbourhood population, with baseline year 2010.

The model was set up in Excel (Microsoft Office 2010) and uncertainty analysis was performed with the add-in tool Ersatz (version 1.3; Epigear International).

Modelling health outcomes

Additional walking in the modelled population was translated into changes in *health adjusted life-years* (HALYs) and incidence/prevalence of physical activity related diseases using a multi-cohort version of a proportional multi-state life table (MSLT) [2]. This MSLT model allows living individuals to be characterized into healthy or diseased states as opposed to the traditional life table that only permits two states (alive or dead). The term ‘proportional’ is in reference to the possibility of including multiple diseases whilst allowing for comorbidities.

Two populations are simulated in the model, the population of interest as it is (or is expected to be in the future, based on observed trends), and an identical population that is exposed to changes in physical activity. Each of these populations has a standard life table with all-cause mortality and sub-life tables for each one of the diseases causally related to physical activity. The Potential Impact Fraction (PIF) is used to link changes in exposure to incidence of physical activity related diseases. The PIF can be defined as the proportional change in disease incidence (or mortality) as a function of a change in exposure to a risk factor for that disease. For example, an increase in physical activity levels decreases the incidence of ischemic heart disease. In the proportional MSLT, this then leads to a decrease in the number of prevalent cases in later years at higher ages. Mortality due to a disease is modelled as a proportion of prevalence, and consequently a reduction in mortality (compared to the non-intervention population) follows a decrease in prevalence.

Changes in HALYs are calculated as the difference of HALYs lived between an Australian adult population that has been exposed to changes in physical activity compared to an identical population that does not experience any changes. HALYs are calculated by dividing both populations into five-year age cohorts groups (20-24 to 95+) and simulating each cohort in the life table until everybody dies or reaches the age of 100. Within the cohort each single year is adjusted for disability attributable to diseases included in the model and for disability caused by all other causes applying estimates for the Australian population [3].

A schematic description of the proportional multi-state life table is presented in Figure 1 only for the counterfactual population in the model (derived from the factual population). In this study, we estimate overall differences in health outcomes by comparing the total number of health-adjusted life years (denoted as Lwx in figure 1) accumulated in the intervention population compared with the non-intervention population. Our ‘health-adjusted life years’ (HALYs) are thus akin to ‘quality-adjusted life years’ (QALYs). We chose the generic term HALYs because the valuation of health states is based on Global Burden of Disease disability weights.

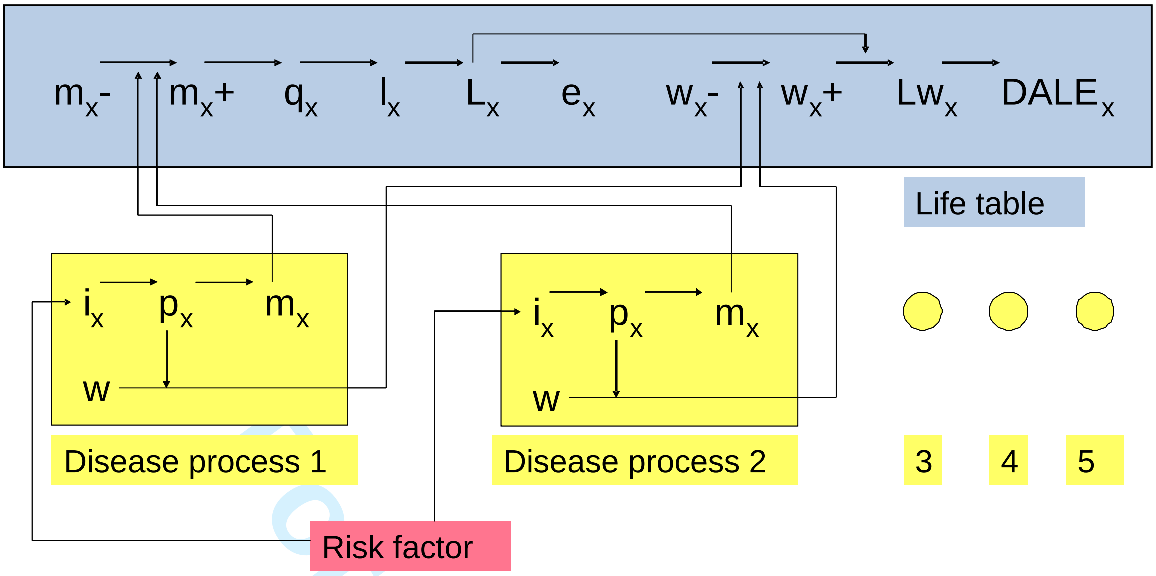

Figure 1 Schematic description of a proportional MSLT, indicating the interaction between life-table parameters and diseases parameters. All the parameters are age specific denoted with x, i is incidence, p is prevalence and m is mortality, w is disability adjustment, q is probability of dying, l is number of survivors, L is life years, Lw is disability adjusted life years and DALE is disability adjusted life expectancy, '-' denotes a denotes parameter related to diseases or causes not included in the models and '-' relates to all modelled diseases included in the model. A change in the determinant of health (physical activity) translates into changes in incidence (i_x), which changes disease specific prevalence (p_x) and mortality (m_x). Changes in prevalence translate into changes in disability adjustments (w).

Changes in diseases

In the MSLT the five physical activity related diseases are modelled applying a set of differential equations to describe the transition between the four states (healthy, diseased, death from the diseases and death from all other causes) [4] (Figure 2). Transition probabilities among the four states are based on rates of mortality, incidence, case fatality and remission. As explained before, the originator of change is incidence. To simplify the process remission is set to zero.

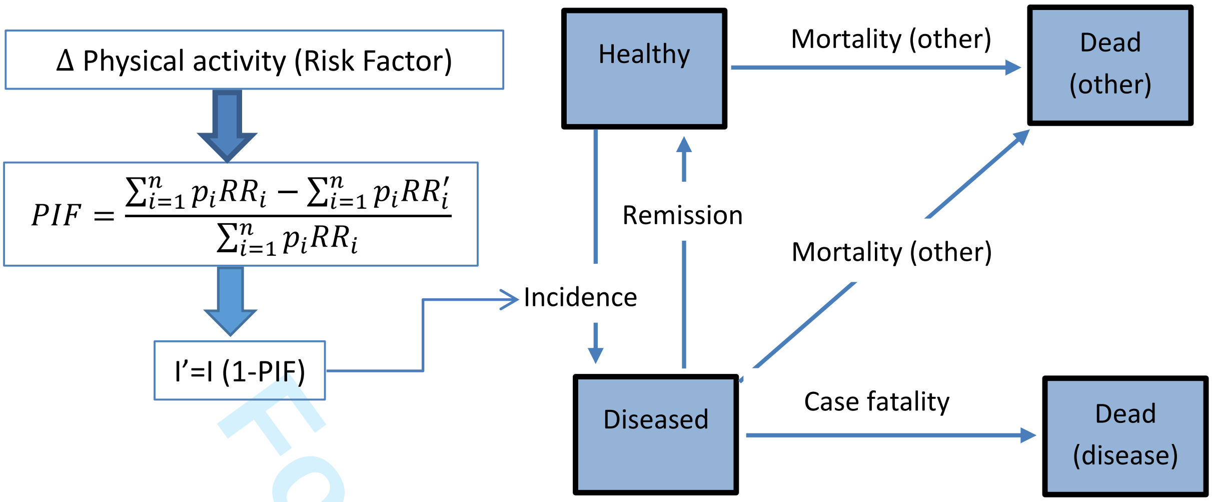

Figure 2 Conceptual disease model used for each of the physical activity related diseases and calculation of new incidence after the intervention. The disease conceptual model has four health states (healthy, diseased, dead from the disease and dead from other causes) and transition hazards between health states [4]. The 'relative risk PIF' [5] was used to estimate new levels of incidence due to changes in physical activity, where p_i is physical activity prevalence at level *i* (3 levels in this research), RR_i is the relative risk of physical activity for each of the diseases associated with *i* and RR_i' is the relative risk of physical activity for each disease associated after the intervention.

Data

Intervention effect (proportion taking up walking and additional minutes per week), epidemiological data and disease-related costs, relative risks of physical activity related diseases, physical activity prevalence, population demography (mortality and population), intervention duration and costs, population density and discounting rates are model input requirements.

Intervention effects were derived from the Heckman model estimates for the association between sidewalk and walking [6].

Epidemiological data for the five physical activity related diseases (ischemic heart disease, stroke, type 2 diabetes, colon cancer and breast cancer in women) were derived from the Global Burden of Disease 2010 study [7] with the help of DISMOD II to obtain parameters not explicitly reported (incidence and case fatality from prevalence and mortality).

Health care costs for the modelled diseases are from the original ACE-Prevention study (Disease Costs and Impact Study 2001 prepared by the Australian Institute of Health and Welfare) inflated applying the Health Price Index [8] (Table 1). Cost were obtained by dividing total cost related to a disease by the number of incident cases (breast cancer and colon cancer) or prevalent cases (ischaemic heart disease, stroke and diabetes type 2). Health care costs due to any other diseases that occur across the life course are included in the same fashion by inflating values from the original model (if people live longer they spend more in health care and the opposite if they live shorter lives).

Table 1 Health care cost per prevalent or incident case of disease

Age	Ischemic heart disease[a]	Stroke[a]	Type 2 diabetes[a]	Breast cancer[b]	Colon cancer[b]
Male					
<55	$3,930	$2,956	$669	-	$23,202
55–64	$2,638	$6,556	$876	-	$23,424
65–74	$2,208	$12,641	$1,012	-	$24,097
75-84	$2,006	$17,055	$848	-	$23,928
85+	$1,850	$21,625	$787	-	$25,588
Female					
<55	$2,430	$1,541	$671	$16,481	$22,733
55–64	$2,017	$2,773	$1,007	$13,921	$21,689
65–74	$2,116	$6,774	$1,113	$15,401	$22,869
75-84	$2,075	$17,427	$988	$16,856	$23,030
85+	$2,216	$26,106	$569	$16,609	$21,949

a. Cost per prevalent case of disease.
b. Cost per incident case of disease.
N.B. Costs are in Australian dollars, from the Disease Costs and Impact Study 2001 prepared by the Australian Institute of Health and Welfare and adjusted to the year 2010 [8].

Relative risks for the five physical activity related diseases are from meta-analyses carried out for the World Health Organization's *Comparative Quantification of Health Risks* [9] (Table 2). As type 2 diabetes is a risk factor for cardiovascular disease, the relative risks from the Asia Pacific Cohort Study Collaboration [10] were applied to estimate the risk of ischemic heart diseases and stroke among those with type 2 diabetes.

Table 2 Relative risks of disease due to physical inactivity

	Age	Inactive	Insufficient	Sufficient
Ischaemic heart disease[a]	15-69	1.71 (1.58-1.85)	1.44 (1.28-1.62)	1.00
	70-79	1.50 (1.38-1.61)	1.31 (1.17-1.48)	1.00
	80+	1.30 (1.21-1.41)	1.20 (1.07-1.35)	1.00
Ischaemic stroke[a]	15-69	1.53 (1.31-1.79)	1.10 (0.89-1.37)	1.00
	70-79	1.38 (1.18-1.60)	1.08 (0.87-1.33)	1.00
	80+	1.24 (1.06-1.45)	1.05 (0.85-1.30)	1.00
Type 2 diabetes	15-69	1.45 (1.37-1.54)	1.24 (1.10-1.39)	1.00
	70-79	1.32 (1.25-1.40)	1.18 (1.04-1.32)	1.00
	80+	1.20 (1.14-1.28)	1.11 (0.99-1.25)	1.00
Breast cancer (in women)	15-44	1.25 (1.20-1.30)	1.13 (1.04-1.22)	1.00
	45-69	1.34 (1.29-1.39)	1.13 (1.04-1.22)	1.00
	70-79	1.25 (1.21-1.30)	1.09 (1.01-1.18)	1.00
	80+	1.16 (1.11-1.20)	1.06 (0.98-1.15)	1.00
Colon cancer	15-69	1.68 (1.55-1.82)	1.18 (1.05-1.33)	1.00
	70-79	1.48 (1.36-1.60)	1.13 (1.01-1.27)	1.00
	80+	1.30 (1.20-1.40)	1.09 (0.97-1.22)	1.00

a. Relative risks of ischaemic heart disease and ischaemic stroke due to diabetes are 2.19 (1.81-2.66) and 2.64 (1.78-3.92) respectively [6].
N.B. Values shown are the mean and 95% confidence intervals.

Prevalence of physical activity per 5-year age/sex group was derived from the National Nutrition and Physical Activity Survey Basic Confidentialised Unit Record File (CURF) [11] with the help of Stata (StataCorp. 2013. *Stata Statistical Software: Release 13*. College Station, TX: StataCorp LP). We weighted the sample data applying person weights provided in the data set. Respondents were asked questions on time spent on four types of activities: walking for transport, walking for fitness, vigorous and moderate physical activity that were then multiplied by the Metabolic Equivalent of Task per minutes (MET-minutes) [12] to obtain weekly energy expenditure (duration of physical activity (mins) * intensity factor walking for recreation/fitness=3.5, walking for transport=3.5, moderate=5, vigorous=7.5). Three categories of physical activity were created according to the weekly energy expenditure: sufficiently active (≥750 MET-minutes per week), insufficiently active (100-750 MET-minutes per week) and inactive (<100 MET-minutes per week) (Figure 3). Average energy expenditure by sex (assumed the same across all age groups) for the calculation of

diseases relative risk per age and sex were obtained by multiplying the corresponding MET minutes by each of the types of physical activity and obtained the average MET-minutes per each of the three physical activity categories.

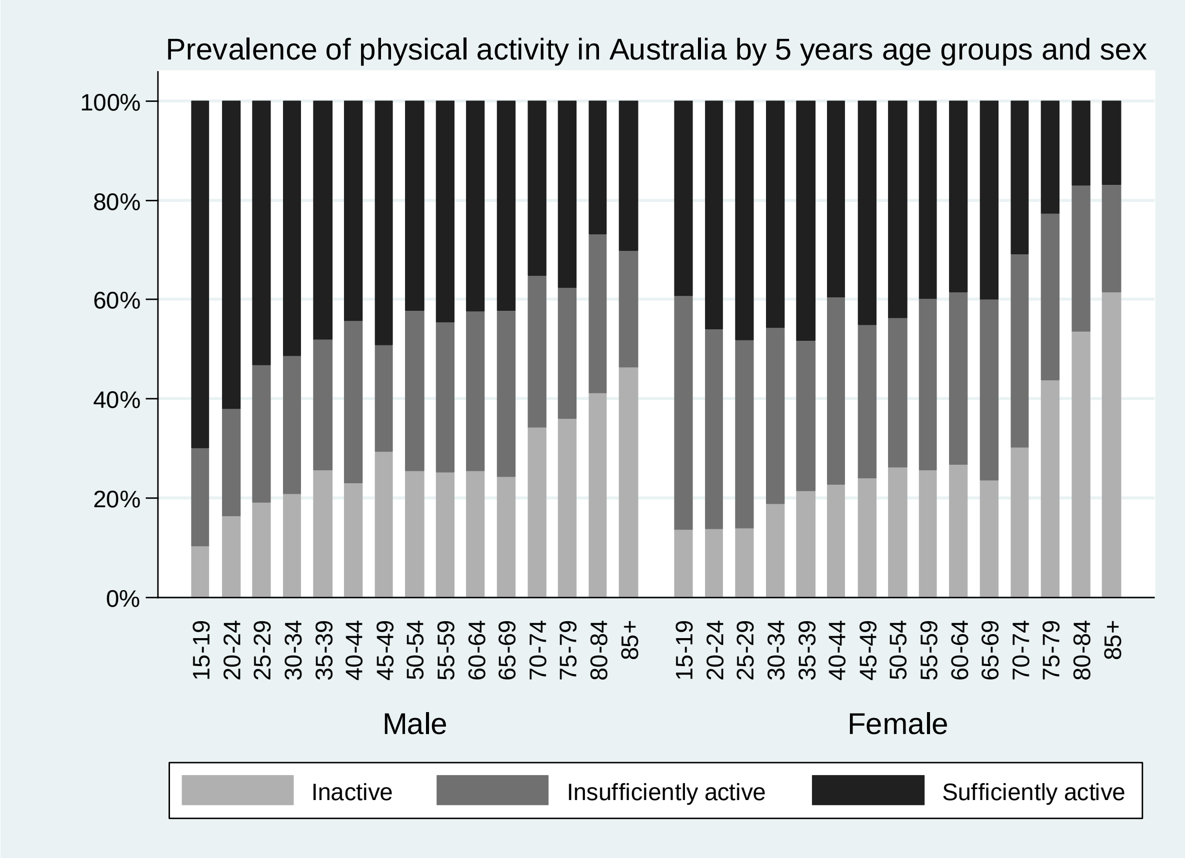

Figure 3 Prevalence of physical activity in Australia (from the National Health Survey 2011-2013)

Population and mortality data inputs are 2010 estimates from the Australian Bureau of Statistics (ABS) [13, 14].

Intervention

For the intervention we used estimates for the population that would be affected by the intervention which we derived from residential density and intervention costs (Table 3).

Table 3 Intervention parameters

Parameter	Value	Source/Comments
Density (net density)		
Base	9 (19,000)[a]	Empirical findings from Falconer et al. [15 p. 288]
For sensitivity analysis		
Low	20 (41,000)	Heart Foundation "Does Density matter?" , 2014, Falconer et al. [15]
Medium	30 (62,000)	Heart Foundation "Does Density matter?" , 2014, Falconer et al. [15]
High	60 (123,000)	Heart Foundation "Does Density matter?" , 2014, Falconer et al. [15]
Sidewalk Cost[b]		
Base scenario	$\$172/\text{m}^2$ (2012/13)	Liverpool City Council [16]
For sensitivity analysis		
Low	$\$150/\text{m}^2$ (2014)	WalksVictoria [17]
High	$\$236/\text{m}^2$ (2012/13)	Liverpool City Council [16]
Useful Life of Sidewalk		
Base	15 years	Quoted by Paul McEvoy in Gunn et al. [18]
Project lifetime		
Base	30 Years	As per in ACE-prevention [19]

a. Based on 2.55 adults per dwelling.
b. Factored to 1.5 meter wide (Liveable Neighbourhood guidelines) and set to baseline year 2010.

Discount rate health and costs

Discounting was applied to health benefits, costs offsets and intervention costs. There has been an ongoing discussion in regards to the appropriate discount rate and whether health benefits should be discounted [20]. Here we followed the recommendations by Gold et al [21] and applied 3% for health benefits and costs (intervention costs and cost offsets) for the base case scenario (the recommendations says 3% or 5%). For sensitivity analyses we varied the discounts rates to 0% for health effects [20] and 5%, and included a scenario in which costs were discounted at 3% and health effects at 1% [22].

Predictive validity

There are multiple techniques to assess the validity of the model. Sargent [23] discusses that a model is developed for a specific purpose and thus its validity should be tested with respect to his purpose. The model developed here assessed how increases in walking affected neighbourhood adult population health, where health was measured using changes in HALYs. The formal validity of the model was checked by several investigators. We tested

for extreme conditions. Specifically, we tested the model outcome when change in walking was equal to zero, and we obtained the expected zero change in outcomes. Moreover, we tested for internal validity by running the model several times to compare the consistency of the results.

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Cost effectiveness of investing in sidewalks as a means of increasing physical activity: a RESIDE modelling study

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ABSTRACT

Background

Studies consistently find that supportive neighbourhood built environments increase physical activity by encouraging walking and cycling. However, evidence on the cost-effectiveness of investing in built environment interventions as a means of promoting physical activity is lacking. In this study we assess the cost-effectiveness of increasing sidewalk availability as one means of encouraging walking.

Methods

Using data from the RESIDE study in Perth, Australia, we modelled the cost impact and change in Health Adjusted Life Years (HALYs) of installing additional sidewalks in established neighbourhoods. Estimates of the relationship between sidewalk availability and walking were taken from a previous study. Multi-state life table models were used to estimate HALYs associated with changes in walking frequency and duration. Sensitivity analyses were used to explore the impact of variations in population density, discount rates, sidewalk costs and the inclusion of unrelated health care costs in added life years.

Results

Installing and maintaining an additional 10 km of sidewalk in an average neighbourhood with 19,000 adult residents was estimated to cost A$4.2 million over 30 years and gain 24 health-adjusted life years (HALYs) over the lifetime of an average neighbourhood adult resident population. The incremental cost-effectiveness ratio was

A$176,000/HALY. However, sensitivity results indicated that increasing population densities improves cost-effectiveness.

Conclusions

In low density cities such as in Australia, installing sidewalks in established neighbourhoods as a single intervention is unlikely to cost- effectively improve health. Sidewalks must be considered alongside other complementary elements of walkability, such as density, land use mix and street connectivity. Population density is particularly important because at higher densities, more residents are exposed and this improves the cost-effectiveness. Health gain is one of many benefits of enhancing neighbourhood walkability and future studies might consider a more comprehensive assessment of its social value (e.g. social cohesion, safety and air quality).

Article summary

Strengths and limitation of this study

- The well-established multi-state multi-cohort life table approach was used to estimate the potential health benefits of investing in sidewalks to encourage physical activity
- Health outcomes considered included reductions in mortality and morbidity, and health-adjusted life years gained
- Findings were adjusted for self-selection effects
- Effect estimates for the association of sidewalk availability with physical activity are potentially subject to recall bias
- Only one interventions is considered in this study, however, to impact on walking and health, there is a need for integrated built environment interventions.

INTRODUCTION

Physical inactivity is an important risk factor for many chronic diseases including diabetes, cardiovascular disease and some types of cancer (1). In Australia, physical inactivity ranks eighth as a risk factor for death and ninth as a risk factor for disability adjusted life-years (DALYs) (2). Yet despite the known benefits, too few adults in Australia (3) and elsewhere (4, 5) participate in levels of physical activity optimal for health. Even small increases in physical activity reduce the risk of chronic disease and provide health benefit (6). Creating supportive built environments can cause positive shifts in population levels of physical activity and significantly reduce the burden of disease and related health care spending (7).

There is increasing attention for the role of the built environment, and in particular neighbourhood urban form, in either facilitating or inhibiting physical activity (8). Several neighbourhood built environment characteristics, including the mix and diversity of land uses and destinations, population or residential density, and street and pedestrian connectivity, are consistently found to be positively associated with physical activity, and in particular walking (9-12). Other built environment attributes are also important for supporting walking such as access to transit, availability and quality of sidewalks/ footpaths, street appeal or aesthetics, and personal and traffic safety (10, 13-17). These built environment characteristics collectively contribute to the ‘walkability’ of a neighbourhood, which is found to be positively associated with walking and other physical activity behaviours (9, 18). Creating ‘walkable’ neighbourhoods would also produce co-benefits and meet other social objectives such as sustainable transportation, reduction in air pollution and traffic noise, and increased social connectivity (19, 20). If these health and social benefits could be realised at a reasonable cost then environmental interventions that improve the walkability of residential neighbourhoods may be a cost-effective means of promoting health and well-being.

There are few economic evaluations of environmental interventions and most of the available evidence relates to designated walking trails or transport-related infrastructure, such as cycle paths (21-23). However, none of these studies adjusted effect estimates for bias introduced by residential self-selection and only one (23) controls for other built environment characteristics. Self-selection refers to the bias introduced by residents who choose to live in neighbourhoods that facilitate walking because they prefer to walk, rather than the neighbourhoods causing them to walk more (24). A systematic review found the median benefit to cost ratio to be 5:1, suggesting that every $1 invested in transport-related infrastructure generates benefits worth $5 (including the financial value of reduced demand on the health care system) (25). Despite this important finding, the authors hesitated from drawing policy-relevant conclusions citing a lack of transparency and variation in the methods employed in studies as a cause for concern. The need to account more accurately for the effect of built environment measures on physical activity was highlighted in a recent systematic review of transport economic evaluations (26).

Others have monetized the health benefits of urban form in relation to walking and health. Boarnet, Greenwald and McMillan (27) used regression analysis on travel survey data from Portland, Oregon, to quantify the impact of built environmental features on distance walked. Walking was translated into lives saved, with each life valued in dollar terms using published estimates of the value of a statistical life ranging from US$2.5 million to US$7.4 million per life saved (US$ 2006). Their analysis suggested that two lives would be saved per year for every 1000 people exposed to a more walkable environment. While this finding is promising, missing from the work was any attempt to quantify the cost of the environmental interventions that might help realise these benefits.

Whilst recognising the need to evaluate the complementary effects of each component of a neighbourhood that collectively enhances walkability, this paper begins this important work by focussing on one aspect, namely the presence of sidewalks. Building sidewalks is something that planners could require in all new housing, and which could be retrofitted in established neighbourhoods.

This study considers the cost-effectiveness of spending to extend the length of sidewalks in a neighbourhood to increase levels of walking and improve health. The effect estimates applied in this modelling exercise were adjusted for other built environment features (implicitly holding all other features of the neighbourhood environment constant) and for residential self-selection, which allows for the evaluation of the independent and unbiased effect of increasing sidewalks. Health Adjusted Life Years (HALYs) were calculated to represent the impact on health of improvements in walking. HALYs are population health measures that combine impacts on morbidity and mortality in a single metric (28).

METHODS

Overview

This economic evaluation involved four stages: 1) estimate the effect of sidewalks on walking; 2) translate the expected increase in walking into a increase in health-adjusted life years (HALYs) gained and health care costs; 3) estimate the costs of extending sidewalk length; and 4) derive estimate of economic value of investing in sidewalks to increase physical activity in terms of the cost per HALY gained. A health sector perspective was used in which the costs of sidewalks (as a health-promoting intervention) were included. An intervention of 30 years duration was assumed, a lifetime time horizon was applied, and costs and benefits were discounted at 3% (baseline scenario) to 2010 values. The 3% rate was chosen following the recommendation by the US Panel on Cost-Effectiveness in Health and Medicine (29).

Estimate of effect of sidewalks on walking

RESIDE data

Data for this stage of the evaluation were drawn from the RESIDential Environments Study (RESIDE) in Perth, Western Australia. RESIDE is a longitudinal study examining the relationship between urban design and a number of social outcomes including physical activity. The opportunity for the RESIDE study arose when, in 1998, the Western Australia state government introduced new planning guidelines (the Liveable Neighbourhood Guidelines) incorporating 'New Urbanist' principles. The RESIDE study followed people relocating to new houses being built in one of 74 new housing developments, some of which were designed according to the Liveable Neighbourhoods guidelines. Information on the RESIDE project is detailed elsewhere (30). The RESIDE dataset contains information on 1,813 people of whom 59% were female, 81% were married or in de facto relationships, 67% have children living at home, 22% were university educated, and 53% were either overweight or obese (average BMI was 26.05) (30).

Model estimates

We took estimates of the relationship between sidewalk length and walking behaviour from the RESIDE cross-sectional baseline survey in this economic evaluation (31) . Data included self-reported neighbourhood-based transportation and recreational walking, socio-demographic characteristics, attitudes towards walking, and variables related to residential self-selection (i.e., access to services, recreation, and schools, pedestrian and cycling friendly streets, and housing variety). Neighbourhood-based transportation and recreational walking had been measured using the Neighbourhood Physical Activity Questionnaire, which provides reliable estimates of the proportion of people who walk and the average minutes spent walking in a usual week, within and outside the neighbourhood (32). This degree of specificity has proved useful in linking walking for different purposes (transport, leisure) with particular neighbourhood attributes. The built environment within 1.6km around participants' homes had been assessed using Geographical Information Systems and satellite imagery to derive objectively-determined measures of neighbourhood walkability (i.e., land use mix, residential density, and street connectivity) (33) and sidewalk length. A Heckman two-staged regression model had then been used to estimate the association between sidewalk length in the neighbourhood and (a) the proportion of people walking for transport or leisure in the neighbourhood, and (b) the total minutes spent walking in the neighbourhood in a usual week among those who reported any walking. McCormack et al. (31) provide a detailed description of the method and results of the Heckman modelling, but in brief, the decision about whether or not to walk was estimated using a multivariate Probit regression followed by a sample selection-bias corrected ordinary least squares regression for minutes spent walking. Estimates of the association between sidewalk length and neighbourhood walking were then adjusted for differences in walkability, attitude towards walking, neighbourhood self-selection , age, gender, and education. McCormack et al. (31) included neighborhood preferences in the probit and linear regression models to adjust for the effect of residential self-selection on walking.

Modelling Health Outcomes and Health Care Costs

To translate the Heckman model estimates of walking as a function of sidewalk length into an estimate of gained HALYs and health care costs avoided we used the mathematical model developed for the Assessing Cost Effectiveness in Prevention (ACE-Prevention) project (34). Baseline health and cost parameters were updated from 2003 to 2010. See supplementary material for further detail.

Gained HALYs and costs were measured over the lifetime of a 2010 Australian neighbourhood adult population. A macro simulation approach was used to calculate changes in HALYs arising from expected changes in physical activity levels due to walking following a hypothetical increase in sidewalk length. We applied a proportional multi-state multi-cohort life table model in which five physical activity related diseases were explicitly modelled, comparing the lifetime number of HALYs for a population that is exposed to the intervention to an identical population under status quo conditions (35). In the proportional multi-state life table model health outcomes are calculated from changes in incidence of physical activity-related diseases (ischemic heart disease, stroke, type 2 diabetes, colon cancer, and breast cancer in women) (1). Changes in incidence of diseases leads to corresponding changes in prevalence in later years, and from there to changes in mortality and years lived with disability. Epidemiological data for the diseases were derived from the Global Burden of Disease 2010 (36) study with the help of DISMOD II (37) to obtain parameters not explicitly reported (incidence and case fatality from prevalence and mortality). The conceptual model for DISMOD II is based on the multi-state life table (38). HALYs are estimated as years of life lived adjusted for health-related quality of life, using Global Burden of Disease disability weights (39) . For more detail, please refer to the Supplementary Material.

Intervention Costs

The intervention was defined as spending to increase the length of sidewalks by 10km in each 1.6 km road network buffer surrounding a participant’s home and maintaining this for 30 years. The cost of installing a standard sidewalk was determined to be A$172 (2012/2013) per square metre based on estimates of actual sidewalk replacement costs obtained from council documents (40-42). Previous research used a value of A$70 per linear meter for a sidewalk of 1.8m in width (16), however, more recent evidence suggests that the price per square meter is likely to be higher (40-42). The initial capital cost and periodic maintenance costs were included, assuming sidewalk replacement after 15 years.

Exposure

More people than just the survey participants will benefit from the investment in sidewalks, and so we also need to take into account residential density to compute the number of people ‘exposed’ to the intervention. Planning guidelines for Perth from 2003 suggest an average residential density of 9 dwellings/hectare in low density areas (43). Assuming an average of 2.55 adults per dwelling, this yields an estimate of 19,000 potential beneficiaries within a 1.6km circular area. We use this figure in our baseline estimate and revisit the assumption in our sensitivity analysis and discussion.

Intervention Cost-Effectiveness

An incremental cost-effectiveness ratio (ICER) is evaluated for the intervention by comparing model outcomes given current levels of physical activity with those that would be expected following an increase in the length of sidewalks in each neighbourhood. The net costs of the intervention are the costs of installing and maintaining the sidewalks plus the net effect that changes in health have on health care costs in future. The reduction in diseases related to physical inactivity lowers treatment cost in the short and medium term, but it also means that new health care costs may be incurred by people who now go on to develop unrelated conditions in their added years of life.

Ninety-five percent uncertainty intervals were determined for all outcome measures by Monte Carlo simulation (2,000 iterations), using the Excel add-in tool Ersatz (Epigear, Version 1.01). Uncertainty distributions around input parameters are described in Table 1. The results of the Monte Carlo analysis were then used to determine the probability of intervention cost-effectiveness against a cost-effectiveness threshold of A$60,000 per HALY, which is a commonly used threshold in the Australian context (44, 45).

Table 1. Uncertainty input parameters

245

Parameter	Mean (SD)	Distribution	Source
Proportion doing any walking	62.40% (19.86%)	Beta	(31)
Extra walkers per additional 10km sidewalk (RESIDE sample)	0.66% (9.68%)	Beta	(31)
Average minutes walked per walker	151.10 (123.15)	Lognormal	(31)
Extra minutes walked per week per 10km sidewalk	5.26 (2.93)	Lognormal	(31)
Disease cost offset	See supplementary material table 1	Uniform	Australian Institute of Health and Welfare Impacts Study 2001. Maximum/minimum assumed at ±25% of mean value
Relative risks of diseases	See supplementary material table 2	Normal (ln RR)	Physical activity (1) and Diabetes risks (46)

246

247 In addition, we vary the cost of sidewalk construction and maintenance, the residential 248 density in the neighbourhood where the new sidewalks are located, and the discount rate 249 in a series of one- and two-way sensitivity analyses. We also combine the cost of 250 sidewalks with residential density to find the most cost-effective mix. All scenarios 251 including the baseline are presented in Table 2.

Table2. Evaluated scenarios

Scenarios	Cost sidewalk per square meter (A\$2010/m^2)	Residential density: dwelling per ha (number of adults*)	Discount rate (%) costs / health	Other health care costs in added life years excluded
1. Baseline	166	9 (19,000)	3	No
2. Low cost sidewalk	136	9 (19,000)	3	No
3. High cost sidewalk	227	9 (19,000)	3	No
4. Low density	166	20 (41,000)	3	No
5. Medium density	166	30 (62,000)	3	No
6. High density	166	60 (123,000)	3	No
7. Low density/ Low cost sidewalk	136	20 (41,000)	3	No
8. Low density/ High cost sidewalk	227	20 (41,000)	3	No
9. Medium density/ Low cost sidewalk	136	30 (62,000)	3	No
10. Medium density/ High cost sidewalk	227	30 (62,000)	3	No
11. High density/ Low cost sidewalk	136	60 (123,000)	3	No
12. High density/ High cost sidewalk	227	60 (123,000)	3	No
13. Discount health 0% and costs 0%	166	9 (19,000)	0	No
14. Discount health 1% and costs 3%	166	9 (19,000)	3/1	No
15. Discount health 5% and costs 5%	166	9 (19,000)	5	No
16. Health care costs prolonged life excluded	166	9 (19,000)	3	Yes

*1.6 km road network buffer

RESULTS

Incremental Cost-Effectiveness

In the baseline scenario, the cost of installing and maintaining an extra 10 km of sidewalks is A$4.1 million per neighbourhood. This investment is expected to gain 24 HALYs over the life span of the neighbourhood adult population (95% uncertainty interval (UI) 20 to 28) (Table 3, Scenario 1. Baseline). After taking into account the net effect on health care costs the total cost increases to A$4.2 million. The incremental cost-effectiveness ratio (ICER) is A$176,000 per HALY gained (95% UI A$148,000 to A$203,000), which lies well above the A$60,000/HALY threshold (Figure 1). Under the baseline scenario assumptions, there was 0% probability of this intervention being under A$60,000 per HALY (Table 4 and Figure 2).

Table 3.Cost Effectiveness Results

Scenarios	HALYs	Intervention cost[b] (A$)	Health care cost offsets[a] (A$)	Costs prolonged life (A$)	Net Cost (A$)	ICER (A$/HALY)
1. Baseline	24	4,077,694	-232,232	313,910	4,159,373	175,782
	(20 , 28)		(-185,343 , -288,222)	(264,636 , 374,670)	(4,134,899 , 4,186,344)	(147,983 , 203,463)
2. Low cost sidewalk	24	3,340,761	-232,232	313,910	3,422,440	144,635
	(20 , 28)		(-185,343 , -288,222)	(264,636 , 374,670)	(3,397,967 , 3,449,411)	(121,911 , 167,330)
3. High cost sidewalk	24	5,576,124	-232,232	313,910	5,657,802	239,115
	(20 , 28)		(-185,343 , -288,222)	(264,636 , 374,670)	(5,633,329 , 5,684,774)	(201,101 , 276,963)
4. Low density	51	4,077,694	-501,132	677,386	4,253,948	83,303
	(44 , 61)		(-399,951 , -621,953)	(571,056 , 808,499)	(4,201,137 , 4,312,149)	(70,416 , 96,162)
5. Medium density	78	4,077,694	-757,809	1,024,339	4,344,224	56,251
	(67 , 92)		(-604,803 , -940,514)	(863,548 , 1,222,608)	(4,264,364 , 4,432,236)	(47,635 , 64,908)
6. High density	154	4,077,694	-1,503,396	2,032,157	4,606,455	30,057

	(132,182)		(-1,199,852 , -1,865,858)	(1,713,168 , 2,425,497)	(4,448,024 , 4,781,059)	(25,527 , 34,652)
7. Low density/Low cost sidewalk	51	3,340,761	-501,132	677,386	3,517,015	68,869
	(44 , 61)		(-399,951 , -621,953)	(571,056 , 808,499)	(3,464,205 , 3,575,216)	(58,276 , 79,413)
8. Low density/High cost sidewalk	51	5,576,124	-501,132	677,386	5,752,378	112,652
	(44 , 61)		(-399,951 , -621,953)	(571,056 , 808,499)	(5,699,567 , 5,810,579)	(95,054 , 130,236)
9. Medium density/Low cost sidewalk	78	3,340,761	-757,809	1,024,339	3,607,291	46,706
	(67 , 92)		(-604,803 , -940,514)	(863,548 , 1,222,608)	(3,527,432 , 3,695,303)	(39,604 , 53,933)
10. Medium density/High cost sidewalk	78	5,576,124	-757,809	1,024,339	5,842,654	75,659
	(67 , 92)		(-604,803 , -940,514)	(863,548 , 1,222,608)	(5,762,794 , 5,930,665)	(63,987 , 87,309)
11. High density/Low cost sidewalk	154	3,340,761	-1,503,396	2,032,157	3,869,523	25,246
	(132,182)		(-1,199,852 , -1,865,858)	(1,713,168 , 2,425,497)	(3,711,091 , 4,044,126)	(21,468 , 29,078)
12. High density/High cost sidewalk	154	5,576,124	-1,503,396	2,032,157	6,104,885	39,840
	(132,182)		(-1,199,852 , -1,865,858)	(1,713,168 , 2,425,497)	(5,946,453 , 6,279,489)	(33,798 , 45,955)

13. Discount health 0% and costs 0%	57	4,980,000	-451,438	815,905	5,344,467	94,735
	(49 , 67)		(-360,947 , -559,008)	(691,928 , 969,496)	(5,279,735 , 5,422,494)	(80,509 , 108,668)
14. Discount health 1% and costs 3%	42	4,077,694	-231,952	580,915	4,426,658	106,881
	(36 to 49)		(-186,346, -284,915)	(495,475 , 683,747)	(4,373,856, 4,489,457)	(92,107 , 122,033)
15. Discount health 5% and costs 5%	15	3,666,193	-159,890	182,938	3,689,241	254,664
	(12 , 17)		(-127,587 , -198,580)	(153,130 , 219,227)	(3,673,755 , 3,706,601)	(213,699 , 295,717)
16. Health care costs prolonged life excluded	24	4,077,694	-232,232	313,910	3,845,462	162,609
	(20 , 28)		(-185,343 , -288,222)	(264,636 , 374,670)	(3,789,472 , 3,892,351)	(134,756 , 190,513)

[a] Negative costs indicate savings.
[b] No uncertainty for intervention costs was assumed.

Table 4. Probability of being under A$60,000 per HALY threshold

Scenario	Probability
1. Baseline	0%
2. Low cost sidewalk	0%
3. High cost sidewalk	0%
4. Low density	0%
5. Medium density	79%
6. High density	100%
7. Low density/Low cost sidewalk	5%
8. Low density/High cost sidewalk	0%
9. Medium density/Low cost sidewalk	100%
10. Medium density/High cost sidewalk	0%
11. High density/Low cost sidewalk	100%
12. High density/High cost sidewalk	100%
13. Discount health 0% and costs 0%	0%
14. Discount health 1% and costs 3%	0%
15. Discount health 5% and costs 5%	0%
16. Health care costs prolonged life excluded	0%

************************(Insert Figure 1 about here) ************************

************************(Insert Figure 2 about here) ************************

Sensitivity Results

The results are extremely sensitive to some of the assumptions made in the analysis, especially in respect to changes in residential density, which materially affects the number of people benefiting from the intervention (Table 4). High residential density, or medium density if the cost of installing sidewalks is low, both generate ICERs consistently below the A$60,000 per HALY threshold (Table 4 and Figure 2). For the medium density scenario, the probability of being under this threshold was 79%.

DISCUSSION

Principal findings

While sidewalks are important in supporting walking, these results show that investing in increasing the length of sidewalks in a neighbourhood, independent of other modifications to create a more walkable neighbourhood, is unlikely to be a cost-effective method of improving health at the existing (low) levels of residential density in Perth. That is to say, other means of increasing physical activity such as GP ‘prescriptions’ for physical activity, social marketing campaigns and supported use of pedometers were estimated to generate health benefits at lower net cost (34).

The analysis is limited to the outcomes associated with the most important diseases related to physical inactivity. Other health benefits, including improved safety for pedestrians, and broader social benefits such as those related to less reliance on motor vehicles, or to any increase in sense of community that results from seeing more of one’s neighbours on the street, have not been included because we lack data on the impact on these measures (47, 48). Thus, one cannot conclude from this work that investing in extending sidewalks is not cost-effective per se. Health gain is, to some extent, an externality or fortunate by-product of decisions that make neighbourhoods more walkable and ultimately more liveable. A more complete evaluation would reflect the value of all outcomes of importance.

The model estimates used for the association between sidewalks and walking also have limitations (31). The estimates of walking, while specific to the neighbourhood context, were self-reported and therefore prone to recall and memory errors. Further, not all walking trips, either for transportation or recreation, are within the neighbourhood. Our context-specific approach, which matched neighbourhood sidewalks with neighbourhood walking, is a strength of this study. However, this approach may underestimate the total influence of sidewalks on walking, as some walking that originated from within the neighbourhood may have also included some walking outside the neighbourhood. Furthermore, sidewalk provision may also support more vigorous-intensity physical activities such as jogging and running, which can provide health benefits over and above those provided by more moderate-intensity physical activity such as walking (49, 50). Since this was a sample of mostly younger and middle-aged people who were about to move into new housing developments in suburban Australia, the external validity of our findings is greatest when applied in similar settings. The more the population of interest differs from out study population, the more caution should be applied in the use of our findings. However, in situations where better suited alternative data are not available, our estimates could serve as a 'best available estimate' if the alternative is no estimate at all, with the risk that the health benefits of walking associated with sidewalks are ignored in the decision making process.

Sidewalk within the broader context

Investment in sidewalks might have a bigger marginal impact on physical activity and produce more health benefits if it were accompanied by complementary efforts to improve other aspects of walkability such as the number and mix of destinations that people can walk to (land use mix), street connectivity and the aesthetic quality of the physical environment. People not only need something to walk on, but also somewhere to walk to. Such a comprehensive approach is likely to have both additive and synergistic benefits as each component of walkability complements the others. It might be also necessary to have other health promotion strategies in place, in addition to the built environment changes, to maximise the impact of this investment on physical activity.

Notably, our results show strongly the importance of residential density. In higher density neighbourhoods the fixed costs of neighbourhood improvements are spread over more people leading to greater overall benefit, which improves cost-effectiveness. By international standards, density in Australia is very low. While one of the aims of the Western Australian Liveable Neighbourhood Guidelines is to increase density, density remained low (43), there is still a demand for large houses on large blocks in Australian cities, with little appetite to mandate higher densities. Nevertheless, policies such as the Liveable Neighbourhood Guidelines are influential in changing practice, and average densities of up to 19 houses per hectare are now being observed in green-field developments in Perth (51). Although that is an improvement over 9 houses per hectare, at 19 houses per hectare the population density is expected to be approximately 40,000 people in a neighbourhood, which implies zero probability for the installation of sidewalks to be cost-effective from the perspective of this study (Table 2).

Other studies found more favourable cost-effectiveness results for sidewalks. For example, using a sophisticated spatial analysis but what they considered a ‘back-of-the-envelope’ economic analysis, Guo and Gandavarapu (23) found that increased sidewalk prevalence in Dane County, Wisconsin, USA, would deliver a cost-benefit ratio of 1.87. The contrast with our findings could be due to a range of factors, including the inability in that study to adjust for residential self-selection, the assumption that additional energy spent on active transport directly translate to lower obesity rates (without dietary compensation) where we modelled the impact via physical activity, and differences in the built environment such as housing density.

Policy implications

Retro-fitting established neighbourhoods to improve walkability is challenging as it involves changing existing infrastructure and housing stock. Such change is often resisted by residential and government bodies and communities. Infrastructure improvements likely to improve health will require a comprehensive long-term strategy involving integrated planning of infrastructure, housing, transport, land use and urban design (52). To this end, the development industry has an important role to play in providing leadership in developing new models for homes in green-field sites that meet the need for more compact developments for a healthier and more sustainable future. Similarly, planning regulations relating to shared occupancy, infill development and housing renewal should aim to increase higher density housing supply, resulting in greater use of existing infrastructure such as sidewalks, transportation, public open space and utilities.

The challenges of retro-fitting existing neighbourhoods and our findings here on the significance of walking draw attention to the need to design pedestrian-friendly neighbourhoods from the outset to facilitate active transport and recreational walking.

CONCLUSION

This work adds to a growing evidence base examining the cost-effectiveness of intervening in the built environment as a means of increasing physical activity and improving health and social outcomes. It points to the potential offered by neighbourhood redevelopment yet highlights the need for a comprehensive strategy that seeks both to improve all elements of walkability including land use mix and street connectivity. In particular it highlights the importance of residential density as a mechanism through which the cost effectiveness of infrastructure is affected because the higher the density, the lower the fixed cost per person who has access to that infrastructure.

COMPETING INTEREST

None to declare.

AUTHORS' CONTRIBUTIONS

A. Shiell, B. Giles-Corti, J.L. Veerman and G. McCormack developed the initial design of the study, oversaw and supervised the empirical work and contributed in drafting the first manuscript. L. Gunn and B. Zapata-Diomedi revised and amended the first manuscript and all authors revised the final version of the paper. L. Cobiac set up the original economic model and B. Zapata-Diomedi revised and updated the economic model with demographic, cost and epidemiologic data, ran the models and wrote the results. B. Zapata-Diomedi drafted the abstract and appendix and J.L. Veerman revised them. L. Gunn, G. McCormack and A. Shiell provided the interventions costs. A.M. Mantilla-Herrera produced the epidemiological estimates. All authors contributed to and commented on the final version of the manuscript.

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DATA SHARING STATEMENT

The model to estimate health outcomes and health care costs is available on request from the first author of this study.

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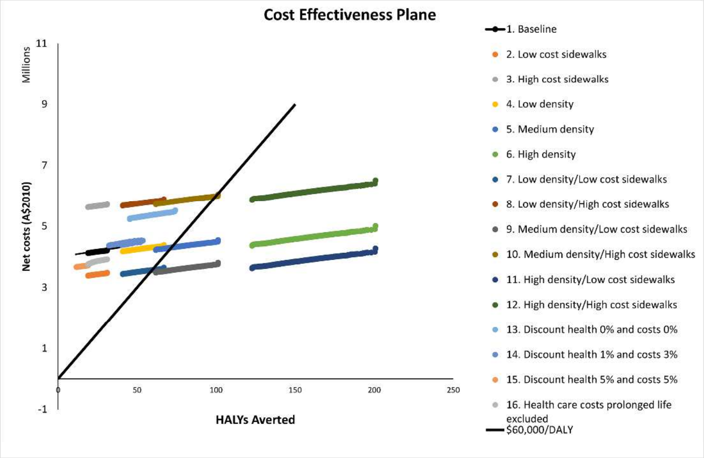
FIGURES

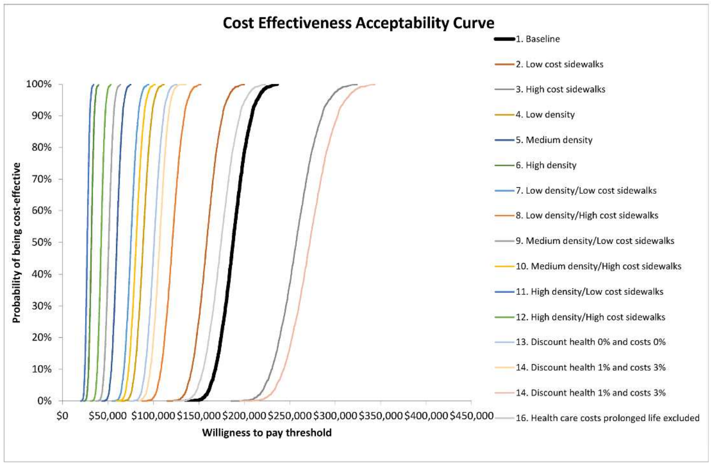
Figure 1. Cost effectiveness plane for investing in sidewalks in a neighbourhood, baseline and alternative scenarios compared to the status quo.

Figure 2. Cost effectiveness acceptability curve for investing in sidewalks in a neighbourhood, baseline and alternative scenarios compared to the status quo.



Cost effectiveness plane for investing in sidewalks in a neighbourhood, baseline and alternative scenarios compared to the status quo

297x420mm (300 x 300 DPI)



Cost effectiveness acceptability curve for investing in sidewalks in a neighbourhood, baseline and alternative scenarios compared to the status quo.

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Cost effectiveness of investing in sidewalks as a means of increasing physical activity: a RESIDE modelling study- Supplementary material

Modelling the cost effectiveness of investing in sidewalks

The original ACE-prevention model [1] was adapted and updated from the original 2003 baseline year to assess the cost effectiveness of adding 10 km of sidewalk in each neighbourhood. The model assesses the cost effectiveness of the intervention for an Australian adult neighbourhood population, with baseline year 2010.

The model was set up in Excel (Microsoft Office 2010) and uncertainty analysis was performed with the add-in tool Ersatz (version 1.3; Epigear International).

Modelling health outcomes

Additional walking in the modelled population was translated into changes in *health adjusted life-years* (HALYs) and incidence/prevalence of physical activity related diseases using a multi-cohort version of a proportional multi-state life table (MSLT) [2]. This MSLT model allows living individuals to be characterized into healthy or diseased states as opposed to the traditional life table that only permits two states (alive or dead). The term ‘proportional’ is in reference to the possibility of including multiple diseases whilst allowing for comorbidities.

Two populations are simulated in the model, the population of interest as it is (or is expected to be in the future, based on observed trends), and an identical population that is exposed to changes in physical activity. Each of these populations has a standard life table with all-cause mortality and sub-life tables for each one of the diseases causally related to physical activity. The Potential Impact Fraction (PIF) is used to link changes in exposure to incidence of physical activity related diseases. The PIF can be defined as the proportional change in disease incidence (or mortality) as a function of a change in exposure to a risk factor for that disease. For example, an increase in physical activity levels decreases the incidence of ischemic heart disease. In the proportional MSLT, this then leads to a decrease in the number of prevalent cases in later years at higher ages. Mortality due to a disease is modelled as a proportion of prevalence, and consequently a reduction in mortality (compared to the non-intervention population) follows a decrease in prevalence.

Changes in HALYs are calculated as the difference of HALYs lived between an Australian adult population that has been exposed to changes in physical activity compared to an identical population that does not experience any changes. HALYs are calculated by dividing both populations into five-year age cohorts groups (20-24 to 95+) and simulating each cohort in the life table until everybody dies or reaches the age of 100. Within the cohort each single year is adjusted for disability attributable to diseases included in the model and for disability caused by all other causes applying estimates for the Australian population [3].

A schematic description of the proportional multi-state life table is presented in Figure 1 only for the counterfactual population in the model (derived from the factual population). In this study, we estimate overall differences in health outcomes by comparing the total number of health-adjusted life years (denoted as Lwx in figure 1) accumulated in the intervention population compared with the non-intervention population. Our ‘health-adjusted life years’ (HALYs) are thus akin to ‘quality-adjusted life years’ (QALYs). We chose the generic term HALYs because the valuation of health states is based on Global Burden of Disease disability weights.

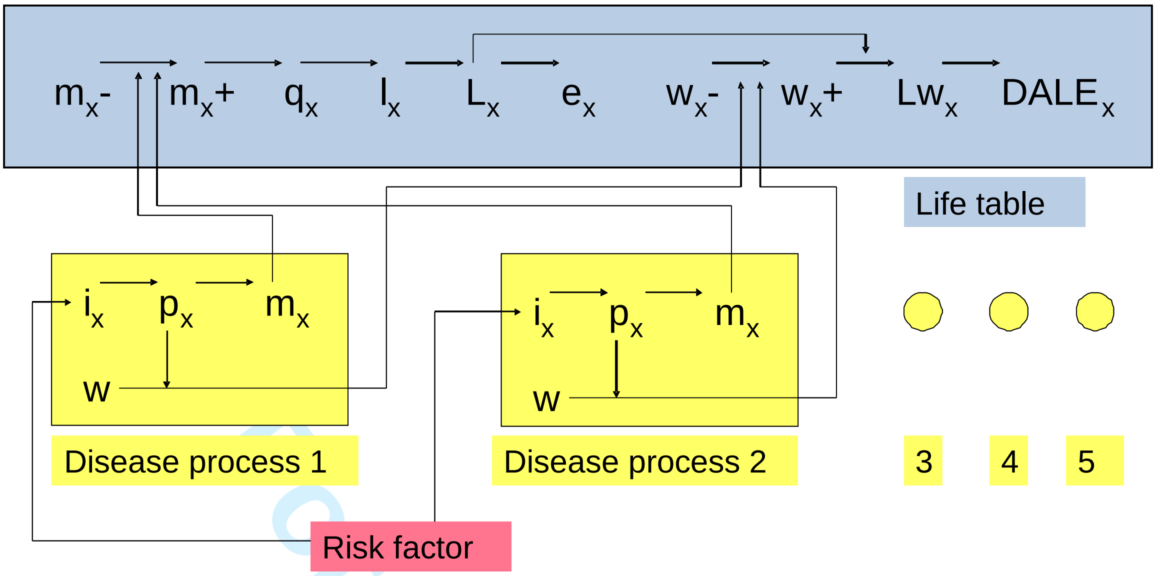

Figure 1 Schematic description of a proportional MSLT, indicating the interaction between life-table parameters and diseases parameters. All the parameters are age specific denoted with x, i is incidence, p is prevalence and m is mortality, w is disability adjustment, q is probability of dying, l is number of survivors, L is life years, Lw is disability adjusted life years and DALE is disability adjusted life expectancy, '-' denotes a denotes parameter related to diseases or causes not included in the models and '-' relates to all modelled diseases included in the model. A change in the determinant of health (physical activity) translates into changes in incidence (i_x), which changes disease specific prevalence (p_x) and mortality (m_x). Changes in prevalence translate into changes in disability adjustments (w).

Changes in diseases

In the MSLT the five physical activity related diseases are modelled applying a set of differential equations to describe the transition between the four states (healthy, diseased, death from the diseases and death from all other causes) [4] (Figure 2). Transition probabilities among the four states are based on rates of mortality, incidence, case fatality and remission. As explained before, the originator of change is incidence. To simplify the process remission is set to zero.

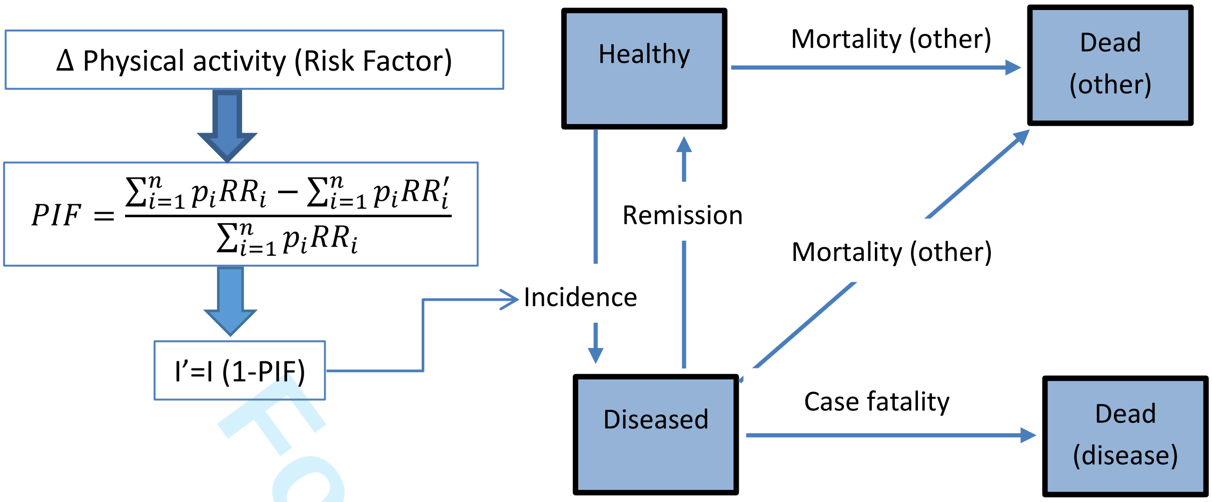

Figure 2 Conceptual disease model used for each of the physical activity related diseases and calculation of new incidence after the intervention. The disease conceptual model has four health states (healthy, diseased, dead from the disease and dead from other causes) and transition hazards between health states [4]. The 'relative risk PIF' [5] was used to estimate new levels of incidence due to changes in physical activity, where p_i is physical activity prevalence at level i (3 levels in this research), RR_i is the relative risk of physical activity for each of the diseases associated with i and RR_i' is the relative risk of physical activity for each disease associated after the intervention.

Data

Intervention effect (proportion taking up walking and additional minutes per week), epidemiological data and disease-related costs, relative risks of physical activity related diseases, physical activity prevalence, population demography (mortality and population), intervention duration and costs, population density and discounting rates are model input requirements.

Intervention effects were derived from the Heckman model estimates for the association between sidewalk and walking [6].

Epidemiological data for the five physical activity related diseases (ischemic heart disease, stroke, type 2 diabetes, colon cancer and breast cancer in women) were derived from the Global Burden of Disease 2010 study [7] with the help of DISMOD II to obtain parameters not explicitly reported (incidence and case fatality from prevalence and mortality).

Health care costs for the modelled diseases are from the original ACE-Prevention study (Disease Costs and Impact Study 2001 prepared by the Australian Institute of Health and Welfare) inflated applying the Health Price Index [8] (Table 1). Cost were obtained by dividing total cost related to a disease by the number of incident cases (breast cancer and colon cancer) or prevalent cases (ischaemic heart disease, stroke and diabetes type 2). Health care costs due to any other diseases that occur across the life course are included in the same fashion by inflating values from the original model (if people live longer they spend more in health care and the opposite if they live shorter lives).

Table 1 Health care cost per prevalent or incident case of disease

Age	Ischemic heart disease[a]	Stroke[a]	Type 2 diabetes[a]	Breast cancer[b]	Colon cancer[b]
Male					
<55	$3,930	$2,956	$669	-	$23,202
55–64	$2,638	$6,556	$876	-	$23,424
65–74	$2,208	$12,641	$1,012	-	$24,097
75-84	$2,006	$17,055	$848	-	$23,928
85+	$1,850	$21,625	$787	-	$25,588
Female					
<55	$2,430	$1,541	$671	$16,481	$22,733
55–64	$2,017	$2,773	$1,007	$13,921	$21,689
65–74	$2,116	$6,774	$1,113	$15,401	$22,869
75-84	$2,075	$17,427	$988	$16,856	$23,030
85+	$2,216	$26,106	$569	$16,609	$21,949

a. Cost per prevalent case of disease.
b. Cost per incident case of disease.
N.B. Costs are in Australian dollars, from the Disease Costs and Impact Study 2001 prepared by the Australian Institute of Health and Welfare and adjusted to the year 2010 [8].

Relative risks for the five physical activity related diseases are from meta-analyses carried out for the World Health Organization's *Comparative Quantification of Health Risks* [9] (Table 2). As type 2 diabetes is a risk factor for cardiovascular disease, the relative risks from the Asia Pacific Cohort Study Collaboration [10] were applied to estimate the risk of ischemic heart diseases and stroke among those with type 2 diabetes.

Table 2 Relative risks of disease due to physical inactivity

	Age	Inactive	Insufficient	Sufficient
Ischaemic heart disease[a]	15-69	1.71 (1.58-1.85)	1.44 (1.28-1.62)	1.00
	70-79	1.50 (1.38-1.61)	1.31 (1.17-1.48)	1.00
	80+	1.30 (1.21-1.41)	1.20 (1.07-1.35)	1.00
Ischaemic stroke[a]	15-69	1.53 (1.31-1.79)	1.10 (0.89-1.37)	1.00
	70-79	1.38 (1.18-1.60)	1.08 (0.87-1.33)	1.00
	80+	1.24 (1.06-1.45)	1.05 (0.85-1.30)	1.00
Type 2 diabetes	15-69	1.45 (1.37-1.54)	1.24 (1.10-1.39)	1.00
	70-79	1.32 (1.25-1.40)	1.18 (1.04-1.32)	1.00
	80+	1.20 (1.14-1.28)	1.11 (0.99-1.25)	1.00
Breast cancer (in women)	15-44	1.25 (1.20-1.30)	1.13 (1.04-1.22)	1.00
	45-69	1.34 (1.29-1.39)	1.13 (1.04-1.22)	1.00
	70-79	1.25 (1.21-1.30)	1.09 (1.01-1.18)	1.00
	80+	1.16 (1.11-1.20)	1.06 (0.98-1.15)	1.00
Colon cancer	15-69	1.68 (1.55-1.82)	1.18 (1.05-1.33)	1.00
	70-79	1.48 (1.36-1.60)	1.13 (1.01-1.27)	1.00
	80+	1.30 (1.20-1.40)	1.09 (0.97-1.22)	1.00

a. Relative risks of ischaemic heart disease and ischaemic stroke due to diabetes are 2.19 (1.81-2.66) and 2.64 (1.78-3.92) respectively [6].
N.B. Values shown are the mean and 95% confidence intervals.

Prevalence of physical activity per 5-year age/sex group was derived from the National Nutrition and Physical Activity Survey Basic Confidentialised Unit Record File (CURF) [11] with the help of Stata (StataCorp. 2013. *Stata Statistical Software: Release 13*. College Station, TX: StataCorp LP). We weighted the sample data applying person weights provided in the data set. Respondents were asked questions on time spent on four types of activities: walking for transport, walking for fitness, vigorous and moderate physical activity that were then multiplied by the Metabolic Equivalent of Task per minutes (MET-minutes) [12] to obtain weekly energy expenditure (duration of physical activity (mins) * intensity factor walking for recreation/fitness=3.5, walking for transport=3.5, moderate=5, vigorous=7.5). Three categories of physical activity were created according to the weekly energy expenditure: sufficiently active (≥750 MET-minutes per week), insufficiently active (100-750 MET-minutes per week) and inactive (<100 MET-minutes per week) (Figure 3). Average energy expenditure by sex (assumed the same across all age groups) for the calculation of

diseases relative risk per age and sex were obtained by multiplying the corresponding MET minutes by each of the types of physical activity and obtained the average MET-minutes per each of the three physical activity categories.

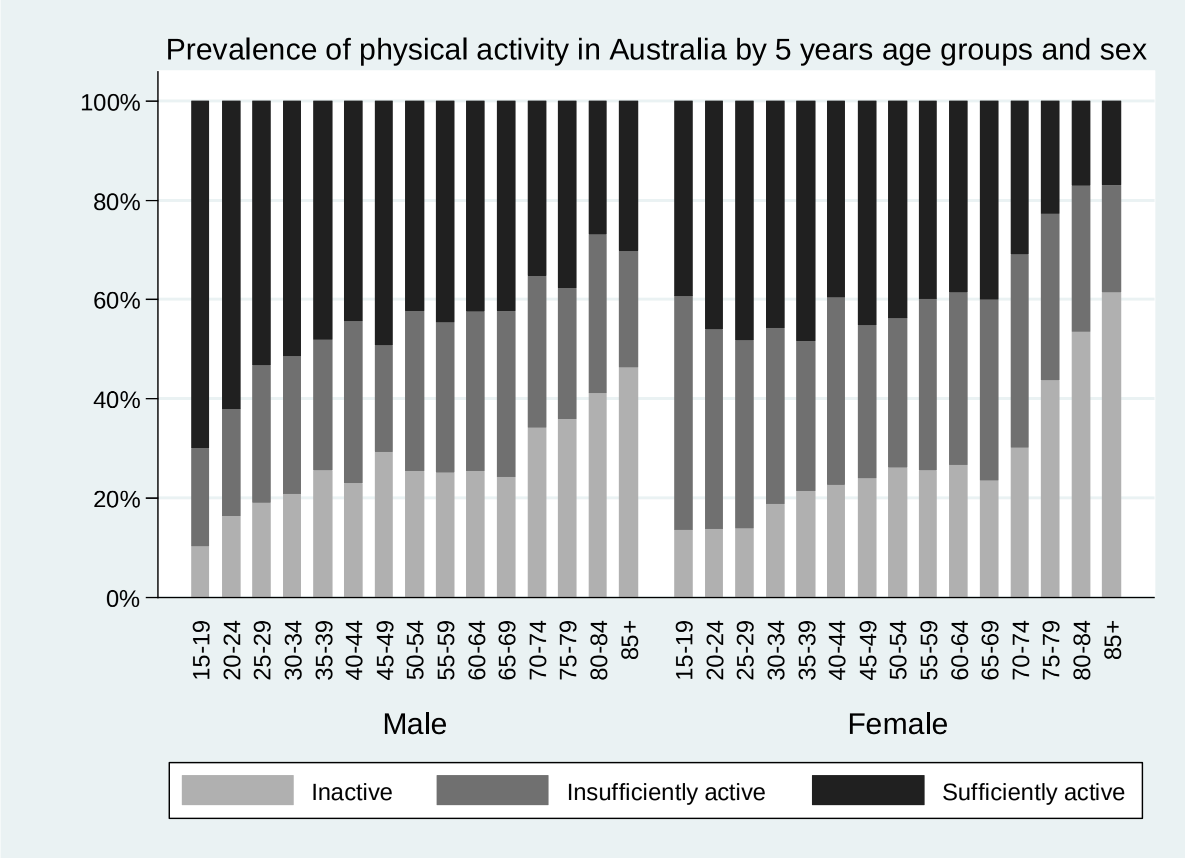

Figure 3 Prevalence of physical activity in Australia (from the National Health Survey 2011-2013)

Population and mortality data inputs are 2010 estimates from the Australian Bureau of Statistics (ABS) [13, 14].

Intervention

For the intervention we used estimates for the population that would be affected by the intervention which we derived from residential density and intervention costs (Table 3).

Table 3 Intervention parameters

Parameter	Value	Source/Comments
Density (net density)		
Base	9 (19,000)[a]	Empirical findings from Falconer et al. [15 p. 288]
For sensitivity analysis		
Low	20 (41,000)	Heart Foundation "Does Density matter?" , 2014, Falconer et al. [15]
Medium	30 (62,000)	Heart Foundation "Does Density matter?" , 2014, Falconer et al. [15]
High	60 (123,000)	Heart Foundation "Does Density matter?" , 2014, Falconer et al. [15]
Sidewalk Cost[b]		
Base scenario	\$172/m^2 (2012/13)	Liverpool City Council [16]
For sensitivity analysis		
Low	\$150/m^2 (2014)	WalksVictoria [17]
High	\$236/m^2 (2012/13)	Liverpool City Council [16]
Useful Life of Sidewalk		
Base	15 years	Quoted by Paul McEvoy in Gunn et al. [18]
Project lifetime		
Base	30 Years	As per in ACE-prevention [19]

a. Based on 2.55 adults per dwelling.

b. Factored to 1.5 meter wide (Liveable Neighbourhood guidelines) and set to baseline year 2010.

Discount rate health and costs

Discounting was applied to health benefits, costs offsets and intervention costs. There has been an ongoing discussion in regards to the appropriate discount rate and whether health benefits should be discounted [20]. Here we followed the recommendations by Gold et al [21] and applied 3% for health benefits and costs (intervention costs and cost offsets) for the base case scenario (the recommendations says 3% or 5%). For sensitivity analyses we varied the discounts rates to 0% for health effects [20] and 5%, and included a scenario in which costs were discounted at 3% and health effects at 1% [22].

Predictive validity

There are multiple techniques to assess the validity of the model. Sargent [23] discusses that a model is developed for a specific purpose and thus its validity should be tested with respect to his purpose. The model developed here assessed how increases in walking affected neighbourhood adult population health, where health was measured using changes in HALYs. The formal validity of the model was checked by several investigators. We tested

for extreme conditions. Specifically, we tested the model outcome when change in walking was equal to zero, and we obtained the expected zero change in outcomes. Moreover, we tested for internal validity by running the model several times to compare the consistency of the results.

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